Crane Catchment Real Time Water Quality Monitoring Project - Final Report

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Acknowledgements

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Contents

Background

The Citizen Crane Project has been monitoring water quality on the River Crane monthly at up to 16 locations since April 2014. The environmental monitoring includes Riverfly Monitoring Initiative (RMI), water quality spot samples analysed at Thames Water's laboratories, and flow measurements. The project delivery partners are the Zoological Society of London (ZSL), Friends of River Crane Environment (FORCE) and Frog Environmental. The steering group includes Thames Water, the Environment Agency and The Crane Valley Partnership. This study was delivered and written up by ZSL on behalf of the Citizen Crane Project.

Thames Water's Smarter Water Catchment (SWC) progarmme started in April 2020 and will continue until April 2030. The Crane Catchment Real Time Water Quality Monitoring Project has been funded by the SWC programme. ZSL hosted the project on behalf of the Citizen Crane Project.

Aims

The aims of the Crane Catchment Real Time Water Quality Monitoring Project were to:

- identify, and prioritise for remedation, sources of pollution in the rivers of the Crane catchment using sondes to collect continuous water quality data,
- learn from the process of using sondes to inform the development of a SWC water quality monitoring plan for the Crane Catchment, and,
- maintain and develop the involvement of the community-based Citizen Crane volunteer network.

Methods

Monitoring equipment, site field resources and data hosting were provided by Meteor Communications. Four Environmental Sensor NETwork (ESNET) portable systems fitted with EXO multiparameter sondes were deployed at a total of 11 locations in the Crane catchment during the period 08/04/2021 to 08/10/2021. One sonde remained in place towards the bottom of the catchment in Kneller Gardens for the duration of the project and three sondes were moved around the catchment. The locations of the sondes can be seen in Table 1.

The sondes were programmed to record water quality parameters every 30 minutes and data were transmitted to a web portal in real time. The sondes measured:

- Temperature (^oC),
- Conductivity (µs/cm),
- pH,
- Ammonium (mg/l),
- Turbidity (NTU),

- Dissolved Oxygen (%).

Sonde data were downloaded directly from the web portal each month, analysed and reported to the steering group. Additional data on rainfall and flow, used in the monthly reports, were downloaded from:

- Rainfall data from Heathrow Airport and Northolt RAF base from Meteostat.net.
- Daily mean flow data from environment.data.gov.uk/hydrology/explore and nrfa.ceh.ac.uk/data/station/meanflow/39057

Five monthly reports were written that summarized the sonde data and highlighted key findings. New sampling locations were decided following analysis of the data and agreement from the steering group. ZSL regularly checked the incoming data to monitor for problems with the sondes, typically data drift due to fouling or buried sondes, and alert Meteor. Meteor recalibrated and cleaned all sondes each month.

Data analysis and visualisation of the full dataset for this final report were conducted using R 4.1.1, a free software environment for statistical computing and graphics (R Core Team 2021). Data visualisation in R was completed using the following packages: ggplot2 (Wickham 2016), dplyr (Wickham *et al.* 2021), and plotly (Sievert 2020).

Table 1: Water Quality Monitoring site details

Site No.	Site Name	NGR	Start date	End date
1	Kneller Gardens	TQ 148 732	08/04/2021	18/10/2021
2	Donkey Wood south	TQ 111 748	08/04/2021	06/05/2021
3	Yeading Brook east	TQ 101 843	08/04/2021	10/06/2021
4	Yeading Brook west	TQ 098 843	08/04/2021	30/07/2021
5	Newton Park West	TQ 127 864	06/05/2021	10/06/2021
6	Downstream Field End CSO	TQ 117 852	10/06/2021	Ongoing
7	Upstream Field End CSO	TQ 123 859	10/06/2021	08/07/2021
8	Crane Park	TQ 131 728	08/07/2021	05/08/2021
9	Donkey Wood north	TQ 109 751	05/08/2021	09/09/2021
10	Duke of Northumberland’s	TQ 110 746	05/08/2021	18/10/2021
11	Cranford Park	TQ 103 781	09/09/2021	18/10/2021

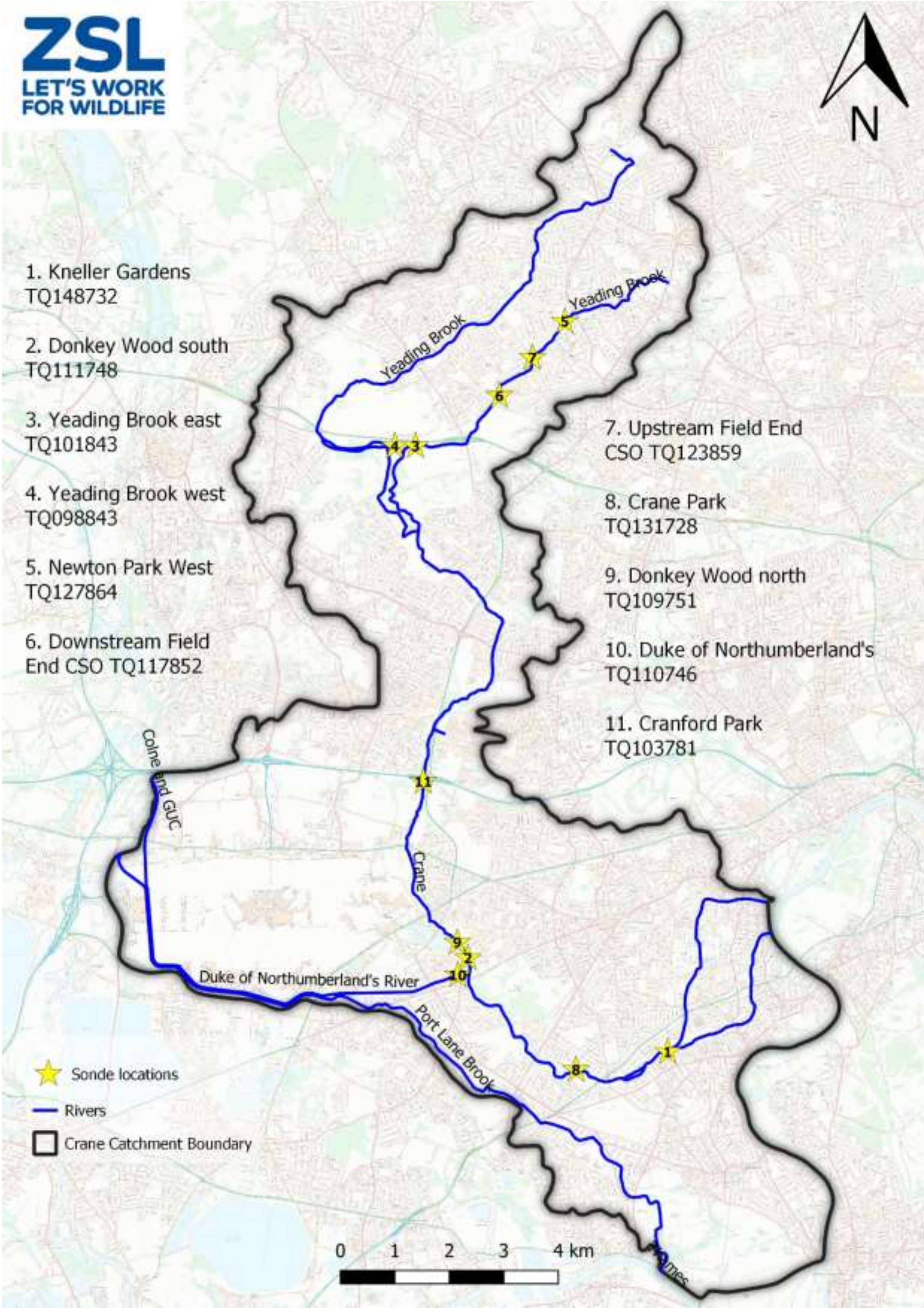


Figure 1: Locations of the water quality monitoring sites in the River Crane Catchment. Map created using QGIS©

Interpretation of the Data

Oxygen

The optical Dissolved Oxygen (DO) sensor fitted to the Exo2 Multiparameter sonde uses a chemical dye which is illuminated by a blue light of a particular wavelength (Exo User Manual). The light immobilises the dye, and it then forms into a disc. The intensity and amount of time the dye is illuminated is measured using a photodiode in the probe, and these measurements give a DO reading. The sensor is reported to be accurate to +/- 1% if the reading is between 0-200%, or +/- 5% if the reading is between 200-500% (Exo User Manual).

DO is the amount of oxygen present in water. The amount of oxygen that can dissolve into water will vary with temperature. When DO is expressed as a percentage, any values over 100 per cent represent super-saturation. Oxygen is essential to all forms of aerobic aquatic life. Due to the critical role it plays in maintaining a healthy freshwater system, DO is often monitored to assess overall ecosystem condition and is a key parameter in Water Framework Directive assessments of water bodies.

DO concentrations in freshwater ecosystems, including rivers, naturally fluctuate based on the time of day: during daylight hours when photosynthesis is taking place, DO increases, and at night when both plants and animals are respiring, DO drops. Due to these natural fluctuations, continuous monitoring is preferred to spot samples as a means of understanding oxygen in a river. Figures 2 and 3 show natural DO fluctuation using two different ways of visualising the data.

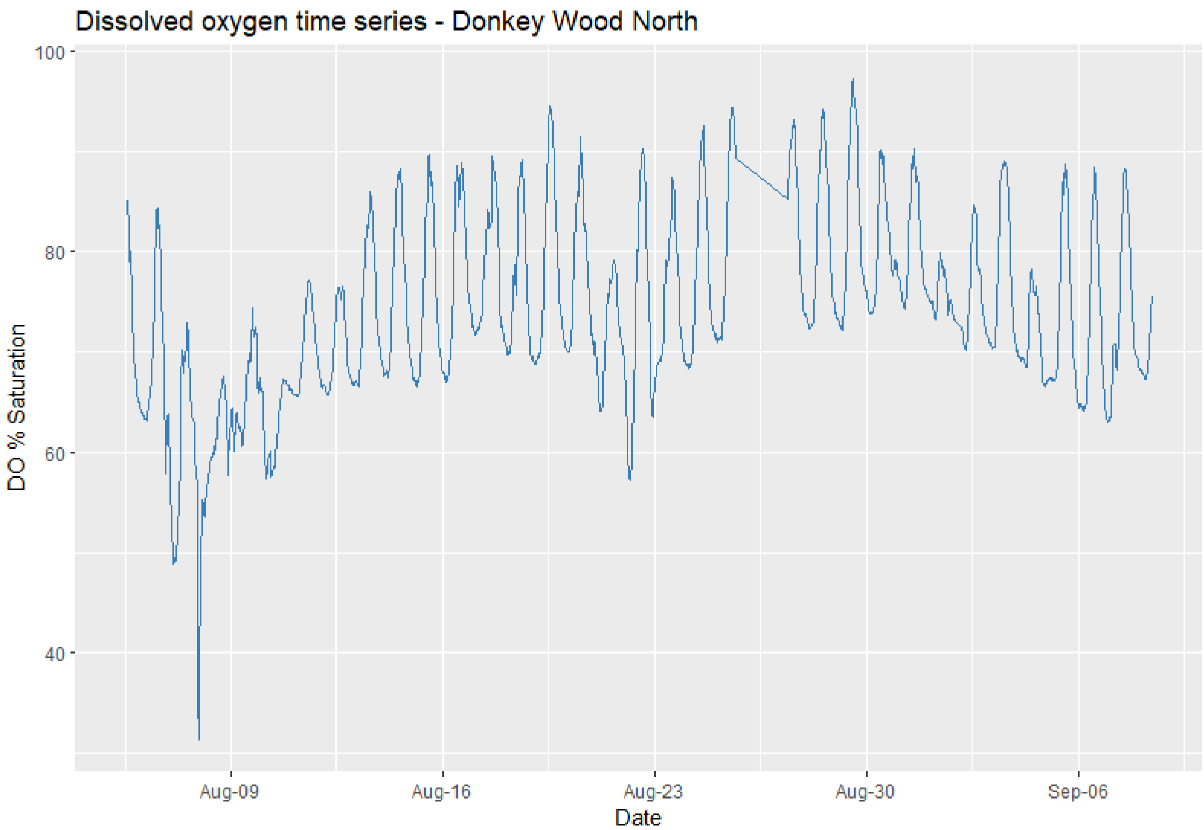


Figure 2: Dissolved Oyxgen time series showing the natural, diurnal fluctuations at Donkey Wood North.

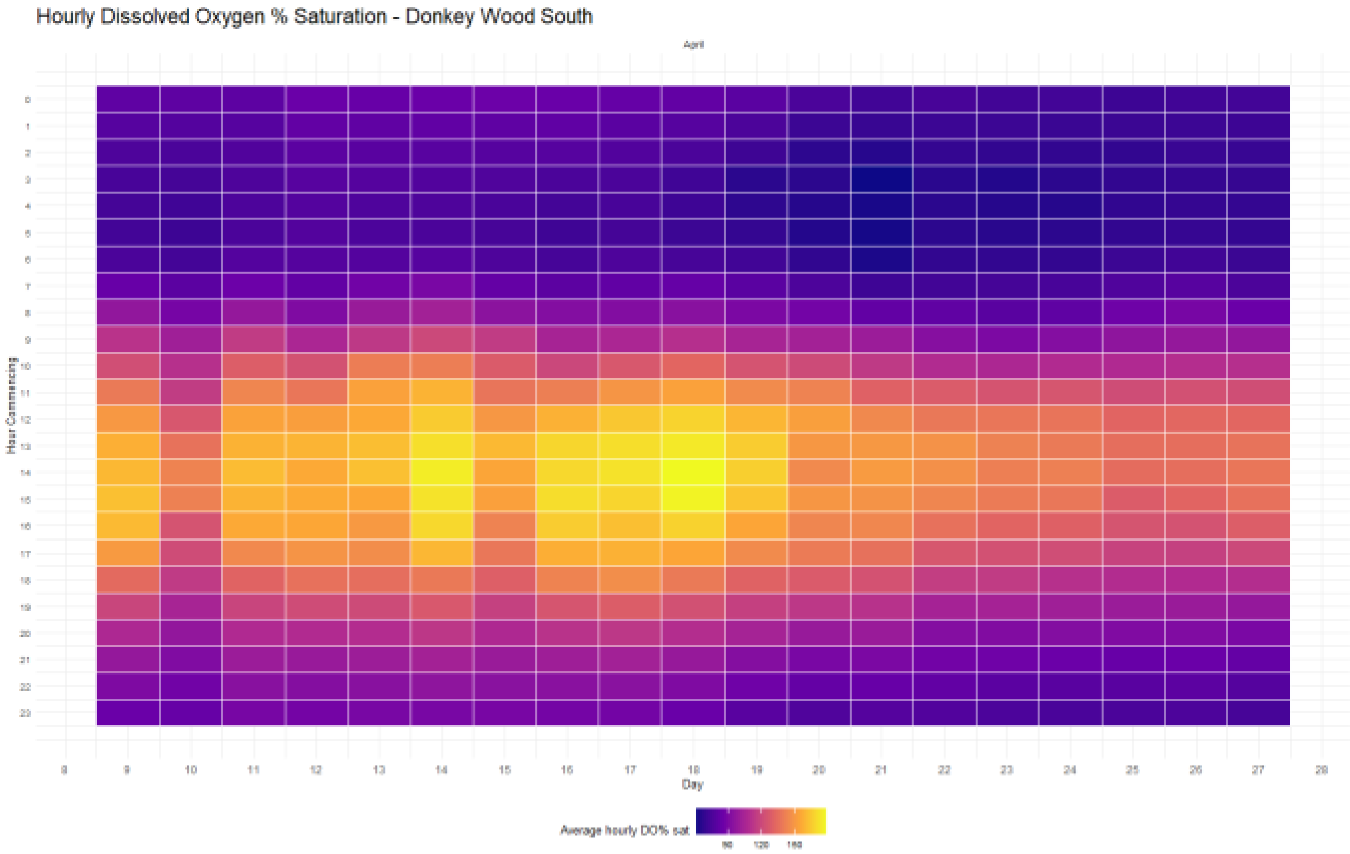


Figure 3: Heat map showing the average hourly DO% saturation for Donkey Wood South in April. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

Rivers impacted by organic pollution events can experience severe drops in DO. The DO drops are caused by a rapid proliferation and influx of microorganisms that are feeding on the organic material and, through their respiration, drawing the DO out of the water. The oxygen used in the decomposition of organic material by microorganisms is known as the Biological Oxygen Demand (BOD) and the oxygen consumed by chemical reactions is termed the Chemical Oxygen Demand (COD). 'First flush' events impact many urban rivers when heavy rainfall follows an extended dry period. Rainwater runs off rapidly into the river and carries with it a wide range of contaminants and pollutants that accumulate during the antecedent dry period (Grimm *et al*., 2005). Figure 4 shows 'first flush' events and the associated drop in DO on September 15th and 30th.

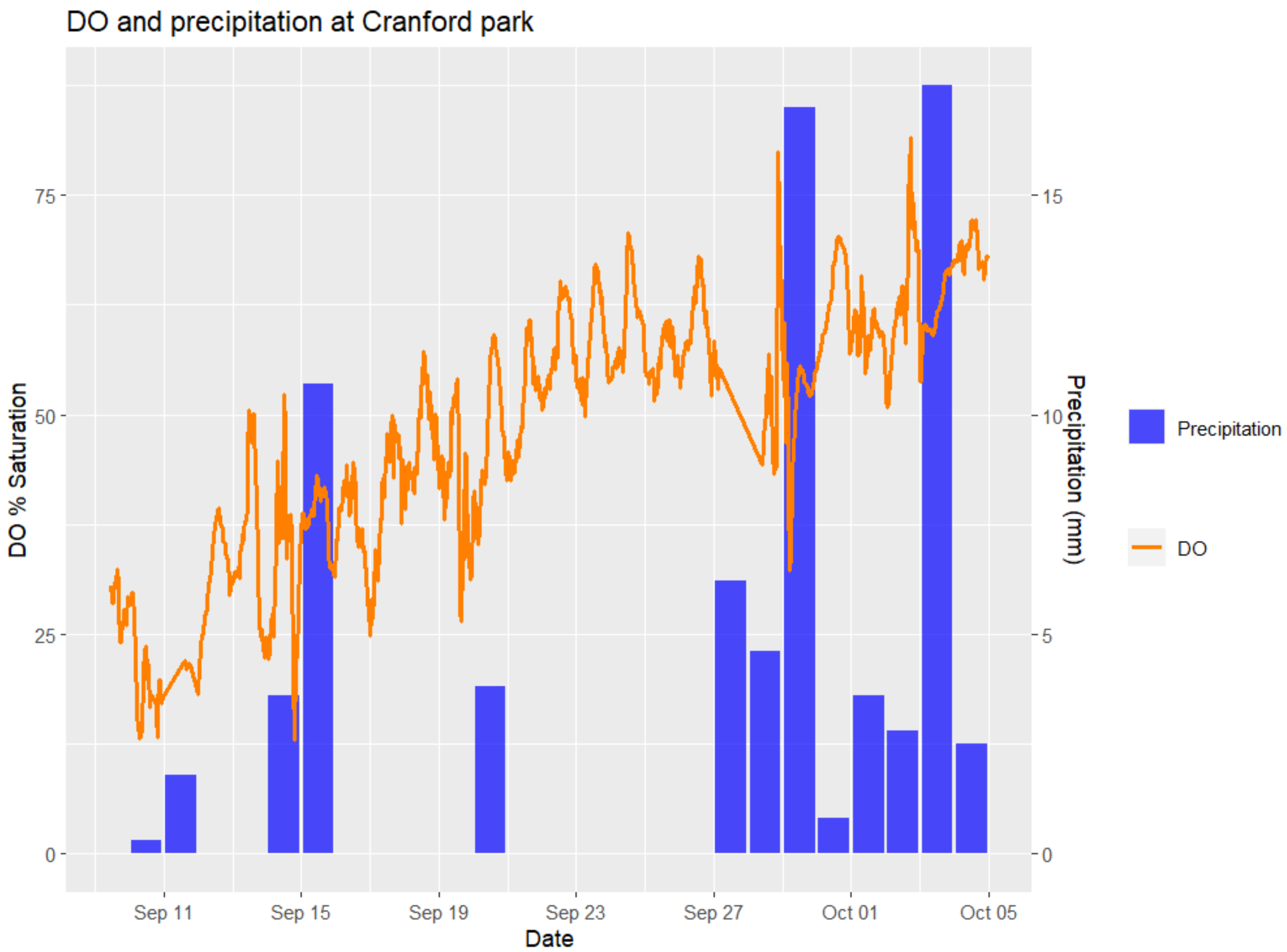


Figure 4: DO % saturation time series plotted over total daily rainfall.

Rivers subjected to chronic inputs of pollution are likely to have sustained periods of low DO. However, both acute pollution, for example caused by CSO discharge after rain, and chronic pollution caused by continuous inputs, can threaten ecosystem function through reducing concentrations of DO. WFD DO classification is based on the 10^{th} percentile of DO (i.e. 10 percent of the data can be lower than the threshold) (UK Technical Advisory Group on WFD 2008). Figures 5 - 8 show the DO ranges and WFD thresholds against the water quality sonde data from Crane Park, Yeading Brook East, Yeading Brook West, and the Upper Duke of Northumberland's River. Table 2 lists the WFD DO river classification for all sites monitored. Note that these classifications are informal and based on monitoring data from a limited time period. They should not be considered as formal WFD assessments for DO, which are carried out by the Environment Agency. Charts showing DO data for all other sites can be found in Appendix 1. Low flows will exacerbate DO issues in river channels.

Eutrophic conditions support high algal biomass which causes extremely large ranges in DO concentration , between supersaturation in the day and very low DO concentrations at night See Figure 6, for example, where in the Yeading Brook East DO ranged between 0% and 210% during the monitoring period.

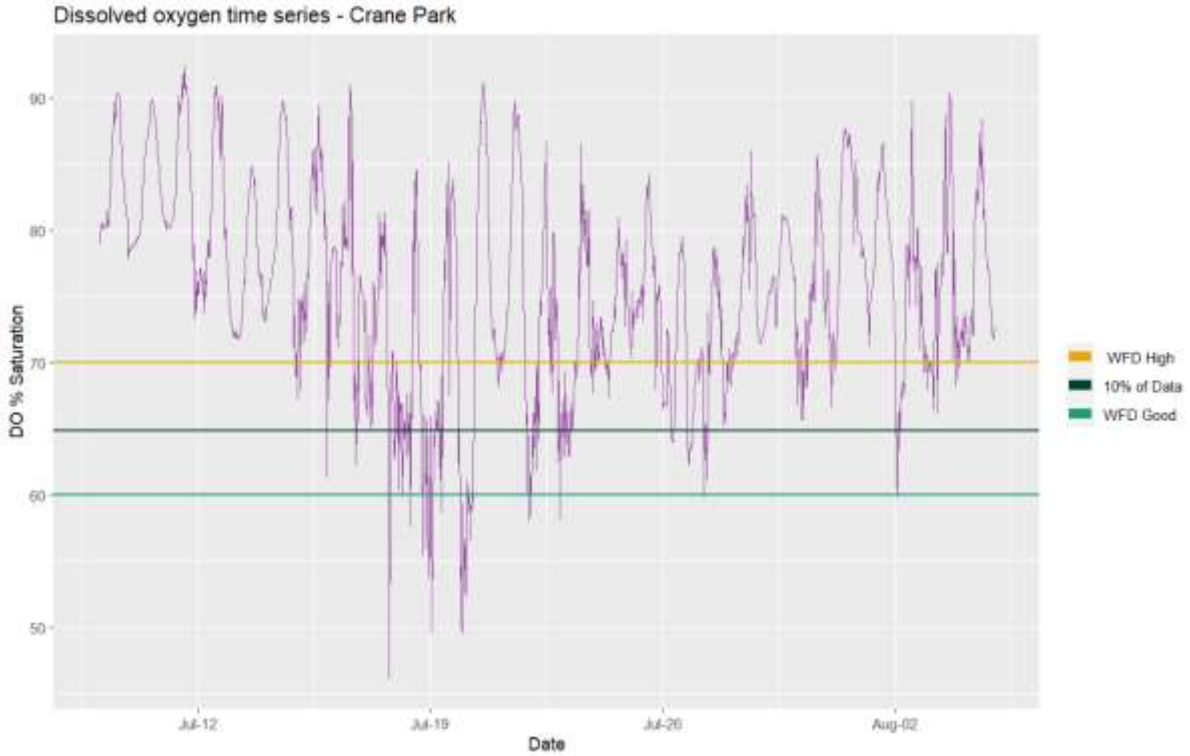


Figure 5: Time series of DO % saturation for Crane Park sonde, with 10th percentile marked in comparison to the nearest WFD standard.

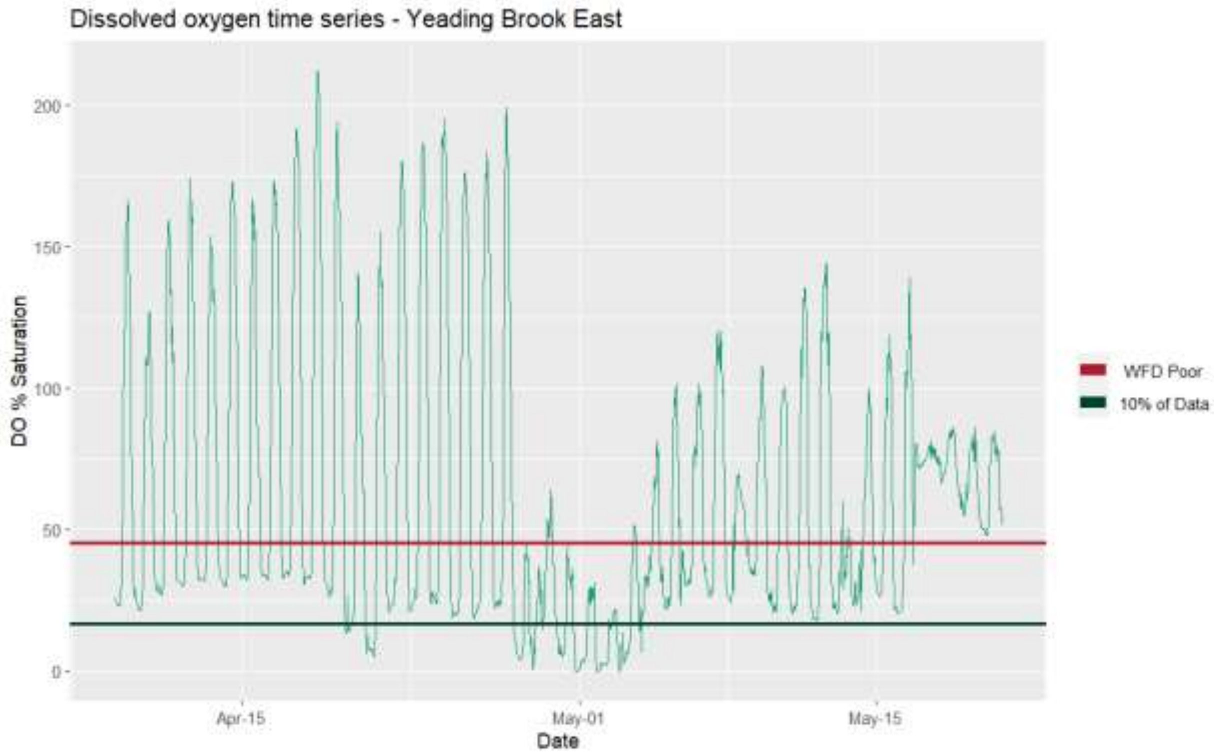


Figure 6: Time series of DO % saturation for Yeading Brook East sonde, with 10th percentile marked in comparison to the nearest WFD standard.

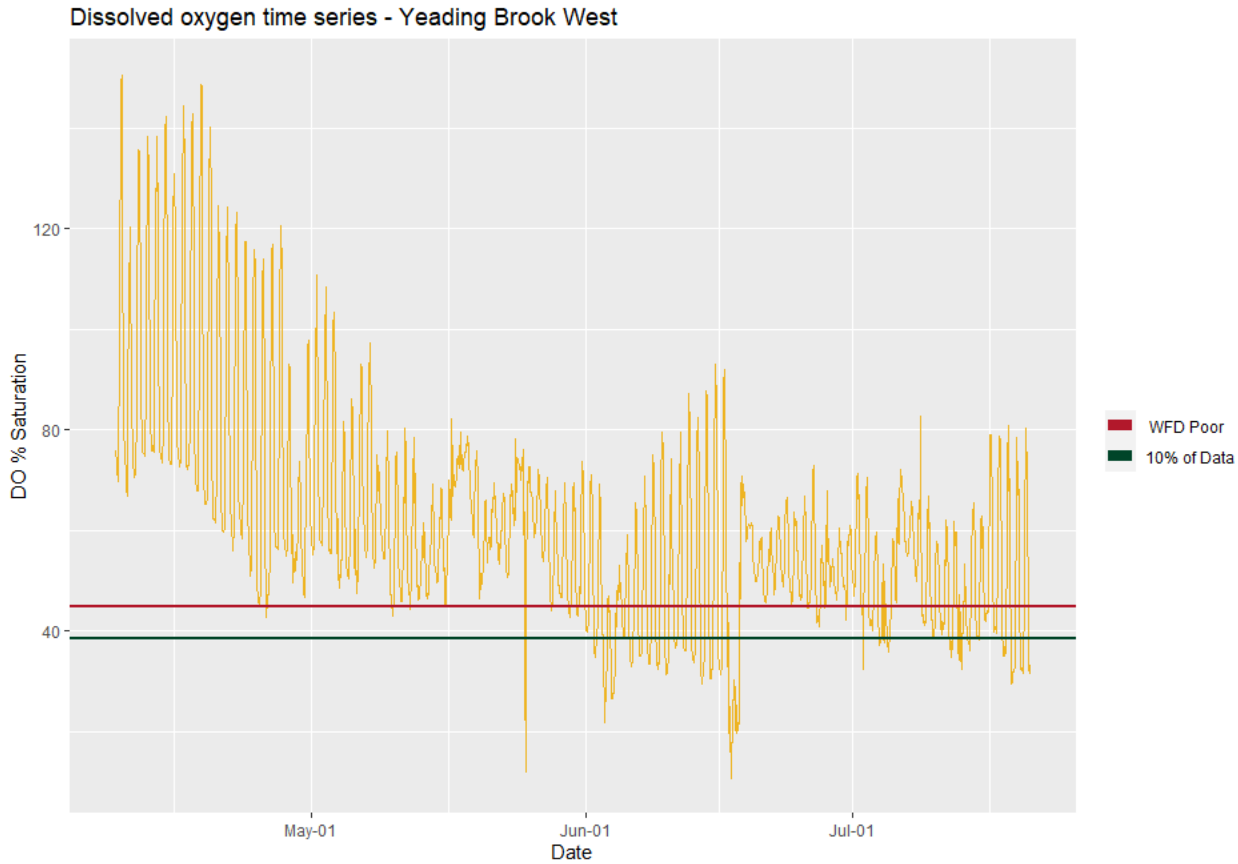
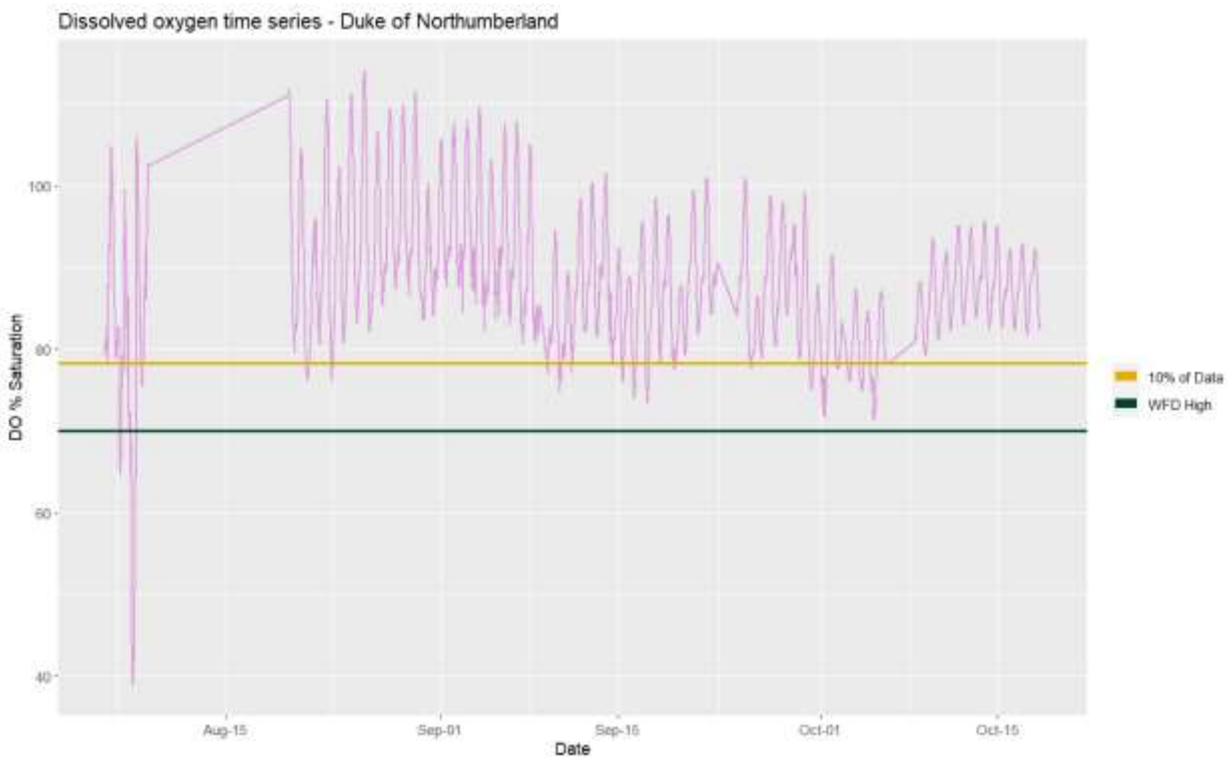


Figure 7: Time series of DO % saturation for Yeading Brook West sonde, with 10th percentile marked in comparison to the nearest WFD standard.



Figures 8: Time series of DO % saturation for Duke of Northumberland sonde, with 10th percentile marked in comparison to the nearest WFD standard.

Table 2: Table showing informal Water Framework Directive Dissolved Oxygen classifications for all sites

Site	**Water Body**	**WFD DO classification**
Kneller Gardens	River Crane	High
Donkey Wood North	River Crane	Good
Donkey Wood South	River Crane	High
Crane Park	River Crane	Good
Cranford Park	River Crane	Poor
Duke of Northumberland (Donkey Wood)	Upper Duke of Northumberland's River	High
Yeading Brook East	Yeading Brook East	Poor
Upstream Field End CSO	Yeading Brook East	Poor
Downstream Field End CSO	Yeading Brook East	Poor
Newton Park West	Yeading Brook East	Poor
Yeading Brook West	Yeading Brook West	Poor

DO concentrations in a river are influenced by many interrelated biotic and abiotic factors. In addition to organic matter, these include ammonium concentrations, algal biomass, temperature, storm events, etc. (Environment Agency 1997; Sánchez *et al.*, 2007). Extended periods of low DO in a freshwater system can have a variety of harmful effects, including reducing organisms' growth rates, raising stress levels, and impairing reproduction. Mortality among invertebrates, fish, molluscs and crustaceans occurs if DO concentrations drop extremely low.

DO data reveal clear evidence of both point source and diffuse inputs of high BOD pollution in the river. A comparison of DO data from sites within the same water body, Yeading Brook East, reveals that 'Downstream of Field End Combined Sewage Overflow (CSO)' has strikingly lower DO concentrations than a nearby upstream site 'Upstream Field End CSO' (see Figures 9 and 10). These data show the effect of an input of pollution between the two monitoring locations and is discussed later in this report.

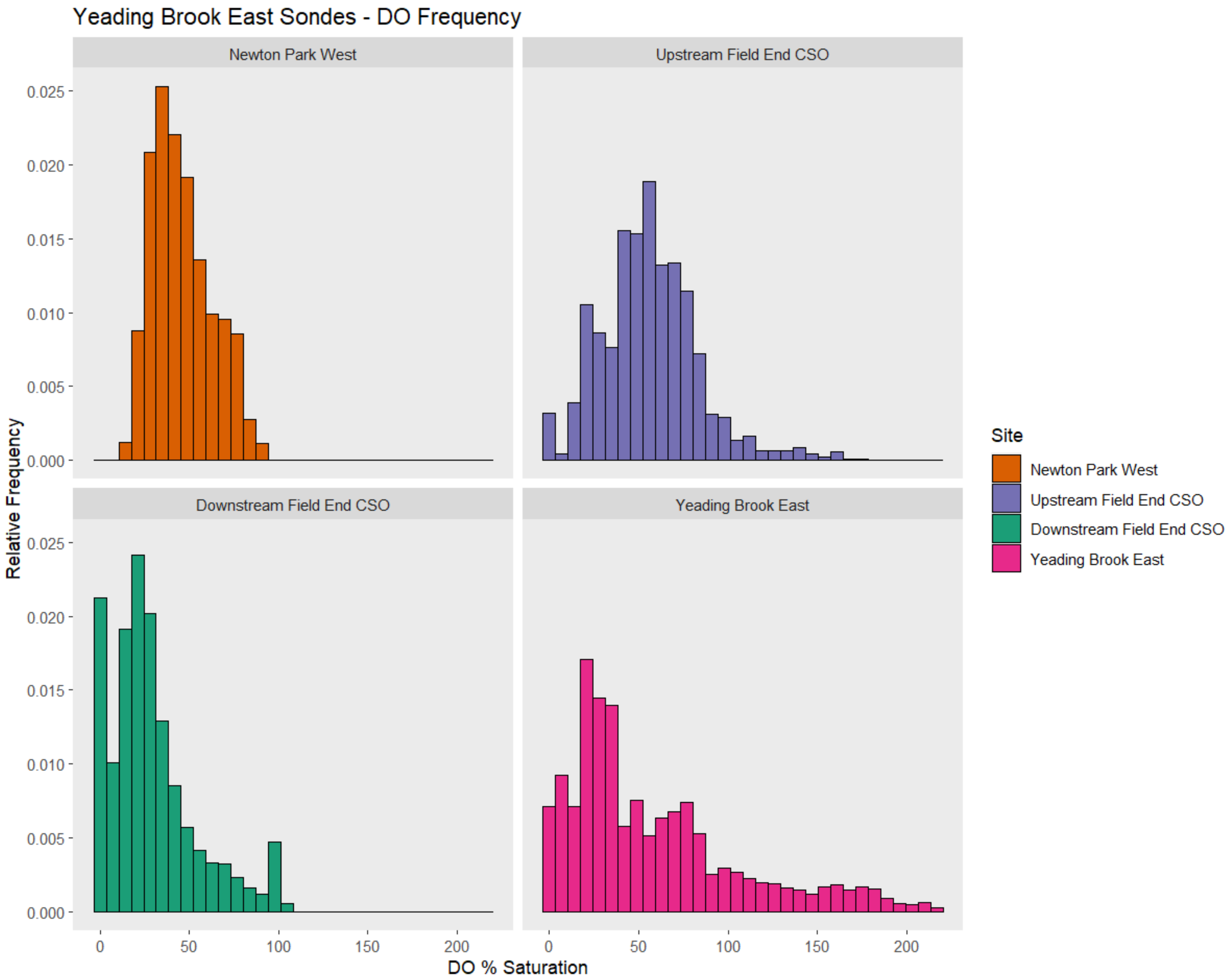


Figure 9: Relative frequency of DO % saturation at all Yeading Brook East sondes. The area of each bar in the histogram represents the percentage of time DO % saturation was within the indicated range.

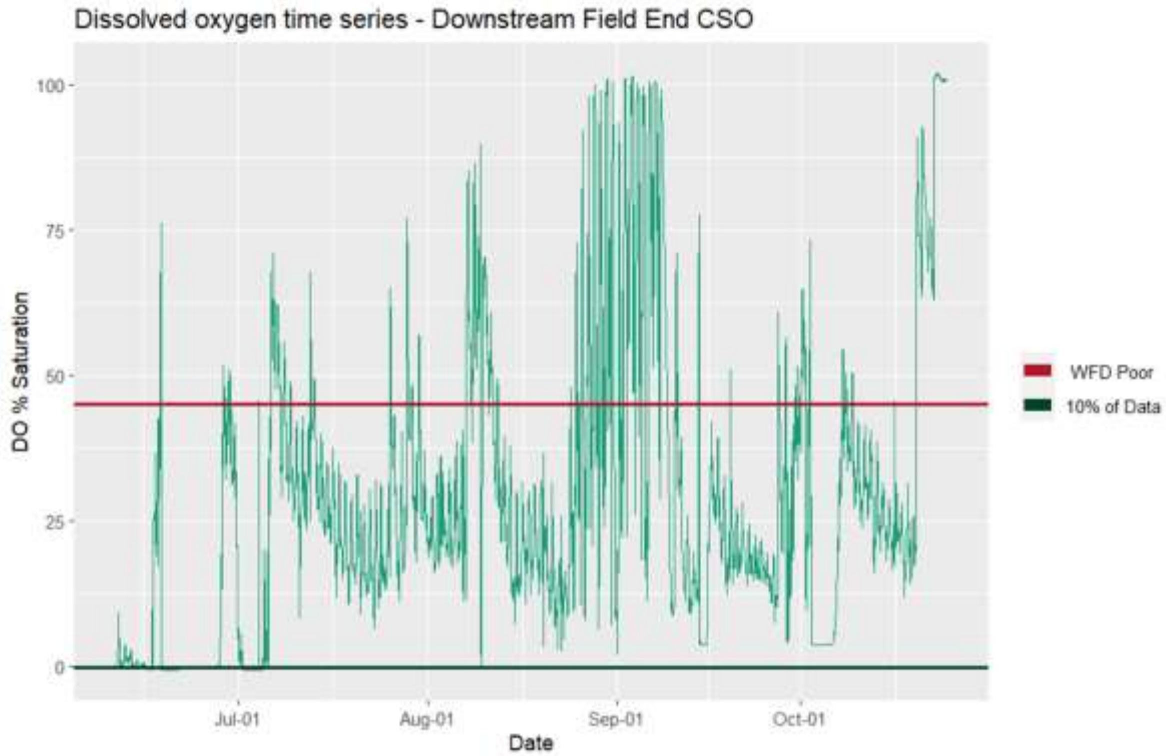


Figure 10: Time series of DO % saturation for Downstream Field End CSO, with 10th percentile marked in comparison to the nearest WFD standard.

Ammonium

The ammonium sensors fitted to the exo multiparameter sonde use ion-selective technology, or the activity of ions in the water column, to measure ammonium concentrations as ($NH4^{+}$ mg/l-N). While ammonium is different to the unionised compound ammonia (NH3), the two are linked (Johnson 2019). Therefore, a high ammonium concentration indicates a high ammonia concentration, and vice versa.

As a result of the decomposition of organic material, ammonium is naturally occurring in small concentrations in unpolluted freshwater environments, and at such concentrations is not harmful to wildlife (EPA 2013). The most common source of ammonium and ammonia, other than natural processes in a river, is waste from humans or farm animals. At higher concentrations in the water column, ammonia poses a direct threat to aquatic life (EPA 2013). Organisms cannot break down ammonia quickly enough, which builds to toxic levels in their blood and tissues (EPA 2013). The WFD sets ammonia standards that freshwater systems must meet, ranging from <0.3mg/l indicating 'High' quality to concentrations >2.5mg/l indicating 'Poor' quality in lowland high alkalinity rivers (WFD 2011).

In addition to its direct toxicity, ammonia, as a component of sewage, will elevate the BOD in a river and therefore reduce the available DO. A study in Oregon, USA, found that a decrease in ammonia was the primary factor that caused an increase in DO in the Willamette River (Dunnette & Avedovech 1983). The relationship between ammonia and DO from the Crane catchment is illustrated by Figure 11.

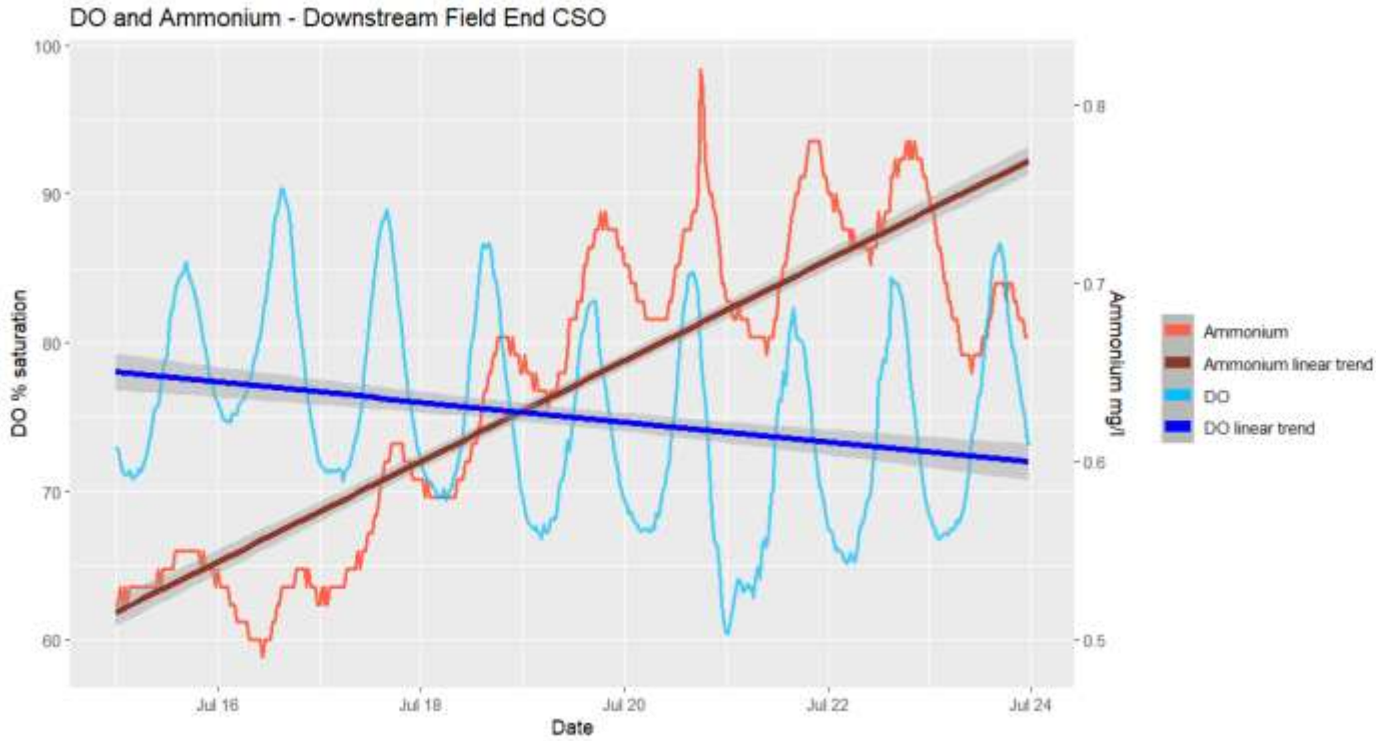


Figure 11: DO % saturation and ammonium (mg/l), with associated linear trends, for Downstream Field End CSO over a 1-week period in July 2021.

Ammonia is more toxic to fish when DO concentrations are low (Becker *et al.* 2009). Declines in macroinvertebrate diversity have also been associated with high ammonia concentrations, among other factors (Johnson 2019). For example, in Ohio, USA, the macroinvertebrate diversity of two rivers of similar dilution was compared. One river was receiving high loads of ammonia-rich urban wastewater and was found to have significantly lower diversity than the other, which was in a more rural setting (Johnson 2019).

On initial analysis of the ammonium data, we observed a noticeable difference between the sensor data and that of the spot samples taken by Citizen Crane volunteers and analysed in a lab. The concentrations from the sensors tended to be significantly higher than the concentrations of water samples analysed in the lab, see Figure 12. Further discussion of this discrepancy with technical experts revealed that ion-selective sensors can be susceptible to interference, impacting the accuracy of their readings. This type of sensor uses an ion-selective membrane, which allows ions to pass through until an equilibrium is reached (Rundle 2000). However, along with the ammonium ion, this membrane can allow other ions to pass through which interfere with the accuracy of the data (Cuartero *et al*. 2020). There are many factors that influence the degree of interference, including temperature and the concentrations of potassium (K+) and sodium (Na+) ions (Crespo 2017). Therefore, an ion-selective sensor placed in a river such as the Crane that regularly has high electrical conductivity, or a high concentration of ions in the water column, is likely to experience interference. This can cause the sensor's ammonium readings to be significantly inflated (1-1.5 mg/l higher) when compared to lab results. However, the degree of this interference has not yet been quantified, and there is no standardised way to offset ion selective sensor results (Capella *et al.* 2020). Therefore, the ammonium data collected by ion-selective sensors are best used to observe general trends, rather than accurate real-time readings (Nick Weddell, pers. comm). It is recommended that sonde data are paired with spot samples to confirm observed trends, and to get a more accurate ammonium concentration (Nick Weddell, pers. comm).

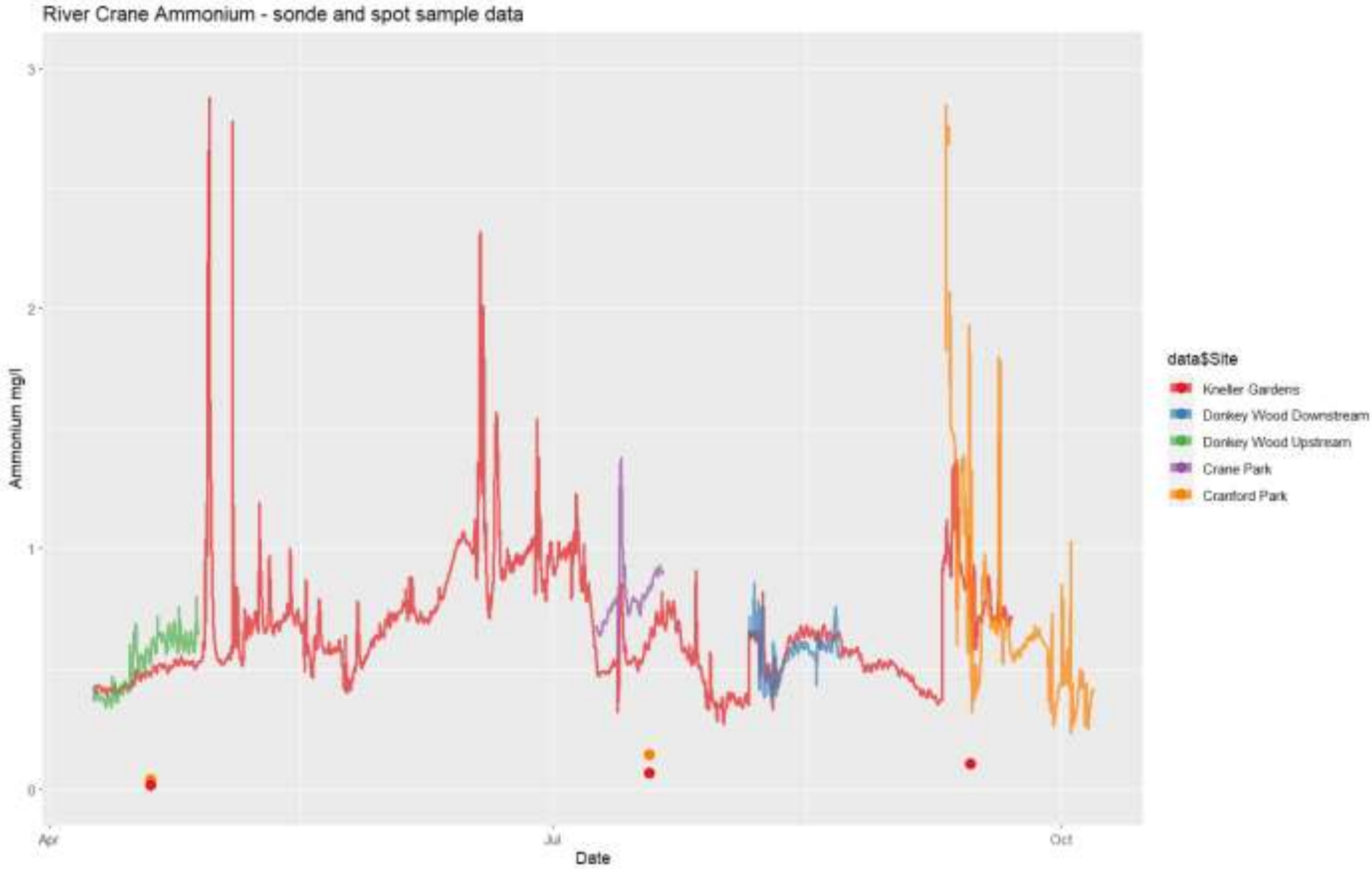


Figure 12: Sonde ammonium time series data for the River Crane and Citizen Crane spot sample data. Spot sample data are coloured according to the sample site and is indicated by the points on the plot. Spot sample data were converted from ammoniacal nitrogen to ammonium.

Due to the poor accuracy of the ammonium sensors used in this project we are unable to classify sites by WFD ammonium standards. However, measuring ammonium concentrations in real-time over long periods has allowed us to compare neighbouring sites to identify sources of sewage pollution between sites (see Figure 13) and to see how the river reacts to different rainfall events and flow conditions.

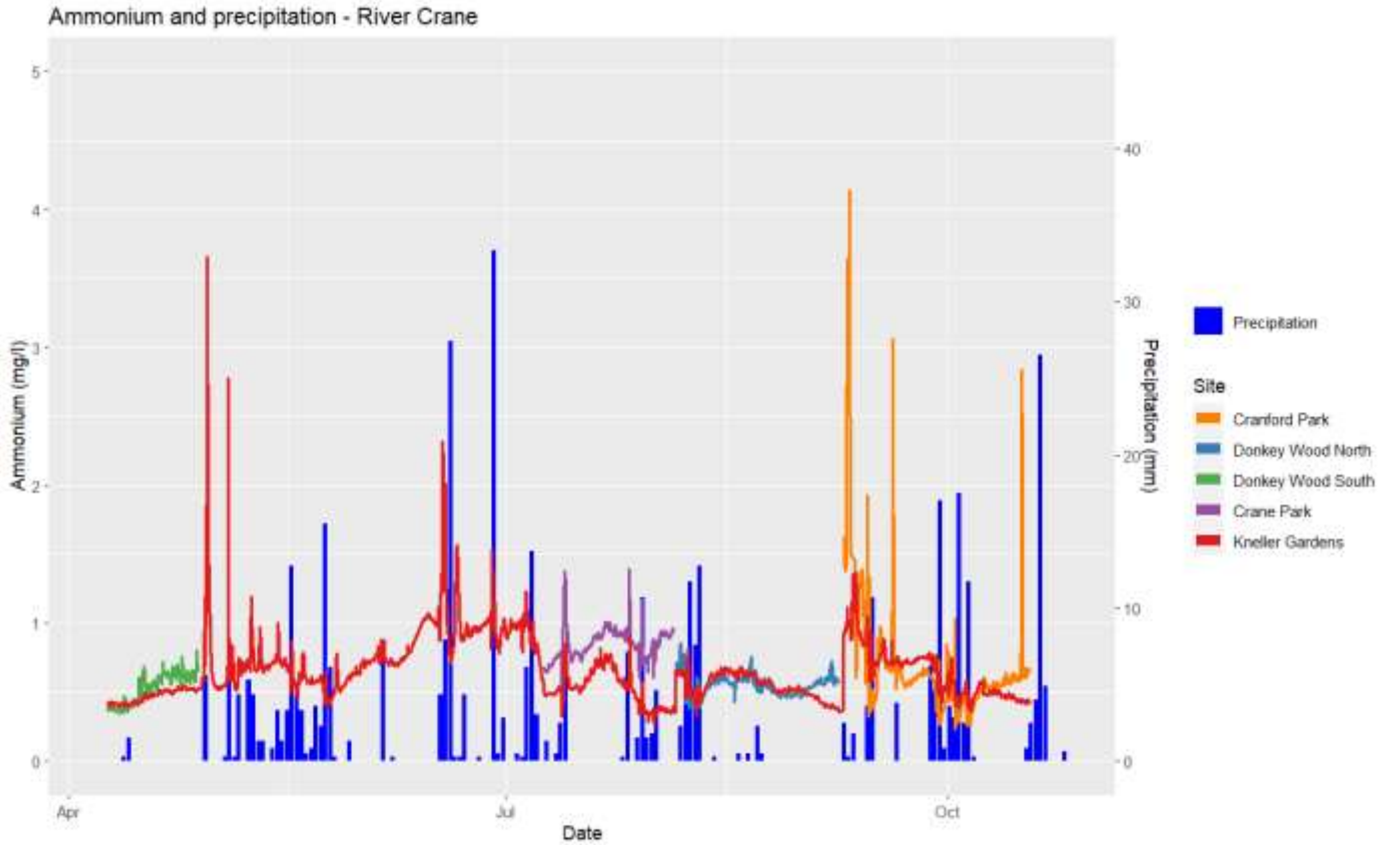


Figure 13: Time series of ammonium concentrations at all River Crane sondes, along with total daily precipitation.

Figure 13 above shows us that ammonium concentrations tend to increase significantly at all the monitoring sites in response to significant rainfall events, suggesting diffuse sources of ammonium are impacting the river. This chart also demonstrates the impact of the 'first flush 'on ammonium concentrations as spikes of ammonium tend to be higher after prolonged periods of dry weather.

Sewage Pollution in the Yeading Brook East

The sonde at Downstream Field End CSO was deployed on 10/06/2021. On 11/06/2021 ammonium peaked at over 40 mg/l (see Figure 14). At the same time, DO fluctuated between -0.6 and 0.8%. This was reported to Thames Water, via the SWC steering group, as a significant pollution issue.

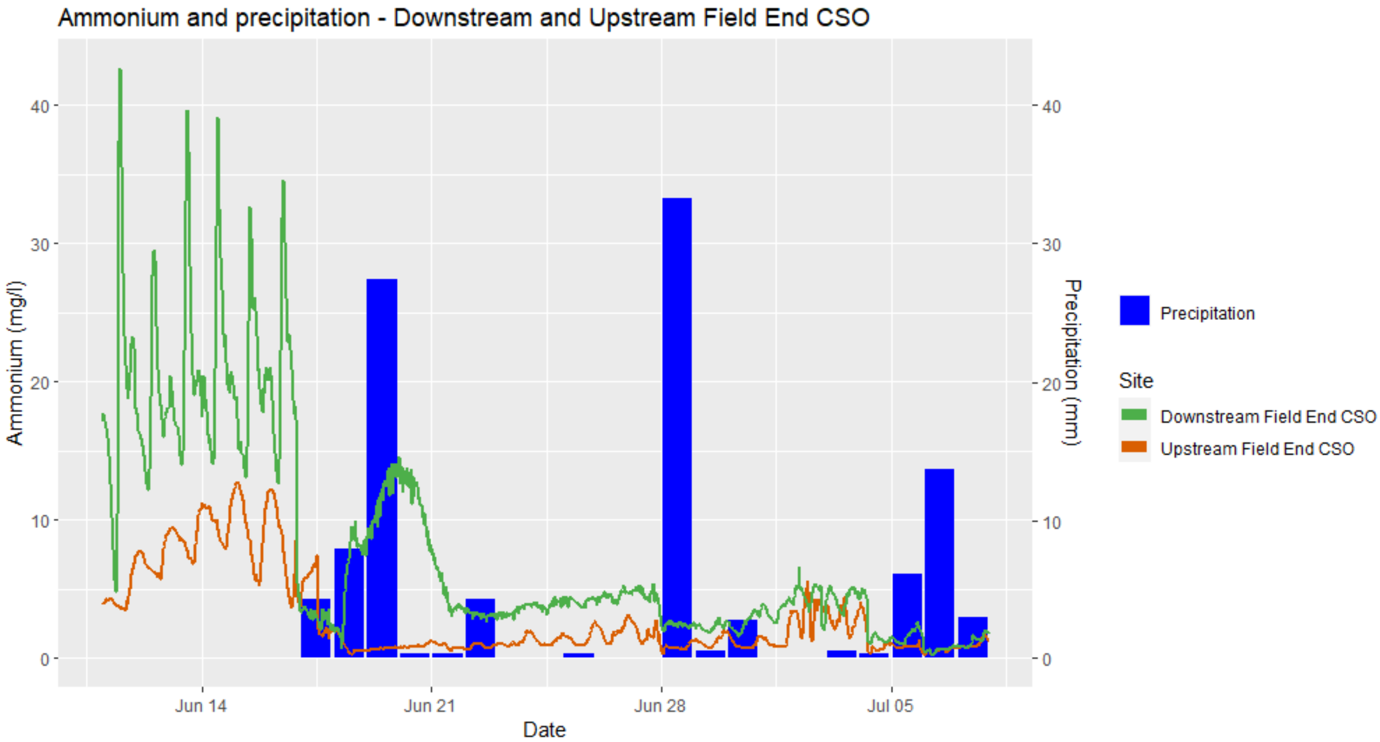


Figure 14: Time series of ammonium concentrations plotted with total daily precipitation at Downstream Field End CSO and Upstream Field End CSO.

By comparing the data downstream of the CSO with the data from above, we came to the following conclusion in the third monthly report issued on 01/07/2021:

> *"Comparing data from upstream and downstream of Field End CSO shows conclusively that there is a source of ammonium between the two sondes – see map below. The timing of the daily peak concentrations of ammonium suggests discharge is occurring during peak demand on the foul sewer network i.e. it is overflowing routinely during the period of maximum use of the foul network. Is this a blockage restricting capacity, a cross connection failure in the upstream foul network or a more worrying under capacity issue in the upstream network?"*

Figure 15: Map showing location of the Upstream (7) and Downstream (6) sondes at Field End CSO on the Yeading Brook East

Figure 16: Photos of (a), Thistledene Avenue, upstream of the culvert, and (b), Field End, Ruislip, during the 2021 Outfall Safari showing extensive sewage fungus covering the riverbed.

On 26/08/2021, during the Outfall Safari, extensive coverage of grey fungus, discoloured water and a strong odour were recorded from outfalls upstream of the culvert, see Figure 16. Downstream of the culvert at Victoria Road, Ruislip (TQ 1172 8538) evidence of the pollution continued uninterrupted for over 1km. This pollution was reported to both Thames Water (reference number 108266344290 and the Environment Agency (reference number 1986368).

Thames Water provided the following update on this pollution incident on 01/10/2021:

> *"Pollution was traced and attributed to a line defect and blockage on Paddock Road, Ruislip. The defect was repaired (relined) and the blockage cleared, and on 10/09/2021 the status was changed to Operational Activity, with a note that all works were complete, and tankers stood down.*
>
> *The booms that were placed on Civic Way (where it emerges from the culvert) were removed by 22/09/2021 as litter and scum was accumulating behind them. Visually the outfall and watercourse downstream were noted to have improved.*
>
> *When visited on 22/09/2021 there was a noticeable improvement at Civic Way and downstream compared to the first two visits (on 27/08/2021 and 03/09/2021). Visually it has improved and hopefully the small remaining areas of sewage fungus will be flushed away with the next rainfall. But the YSI readings from Thistledene Avenue and Civic Way (immediately before and after it is culverted) suggest that there are additional sources of pollution in the culverted section (possibly misconnections). Further downstream (between sampling locations 2 and 3) is the input from the unmapped outfall from the Suez waste site – [Caitlin Curry] is unsure if the EA have visited or made any progress with their investigation."*

Table 3: Data provided by Thames Water on 01/10/2021

	NGR	Date	DO (%)	NH3 (mg/l)	NH4 (mg/l)	Comments (22/09/2021)
Sample location 5 – Thistledene Avenue	TQ 12404 86009	27/08/21	140	0.12	1.01	Upstream of Civic Way, immediately before it is culverted.
		03/09/21	141	0.07	0.64	
		22/09/21	87.6	0.02	0.92	
Sample location 1 – Civic Way	TQ 11724 85383	27/08/21	42.7	0.17	6.85	Visually it has improved. Some scum present on the surface and some sewage fungus remains downstream in slower moving areas of stream.
		03/09/21	59.1	0.06	3.45	
		22/09/21	41.3	0.05	3.26	
Sample location 2 – bridge to rear of Volkswagen garage	TQ 11753 85281	27/08/21	29.6	0.07	3.77	Upstream of Suez waste site. No visual sewage fungus.
		03/09/21	25.8	0.06	4.17	
		22/09/21	32.8	0.04	2.80	

Sample location 3 – Field End bridge	TQ 11484 84991	27/08/21	23.2	0.10	5.20	First sampling location downstream of Suez waste site. Visually it has improved, with little sewage fungus.
		03/09/21	27	0.07	4.72	
		22/09/21	23	0.05	4.18	
Sample location 4 – Polish War memorial	TQ 11009 84517	27/08/21	9.8	0.11	6.78	Downstream of Masson Avenue SW outfall, but the loading shouldn't be too high from that. No longer discoloured and has lost the strong slurry odour (which was noticeable on the previous two visits). The visual/odour improvements are reflected in the water quality readings.
		03/09/21	11.5	0.09	10.61	
		22/09/21	16.9	0.05	3.69	

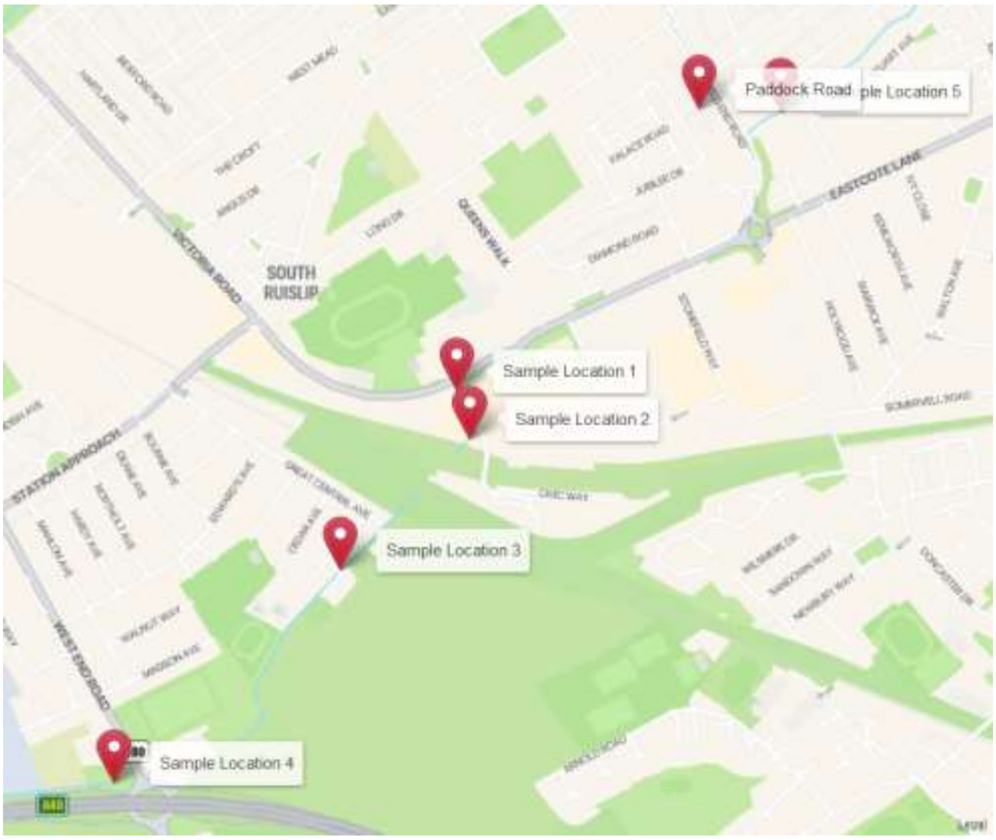
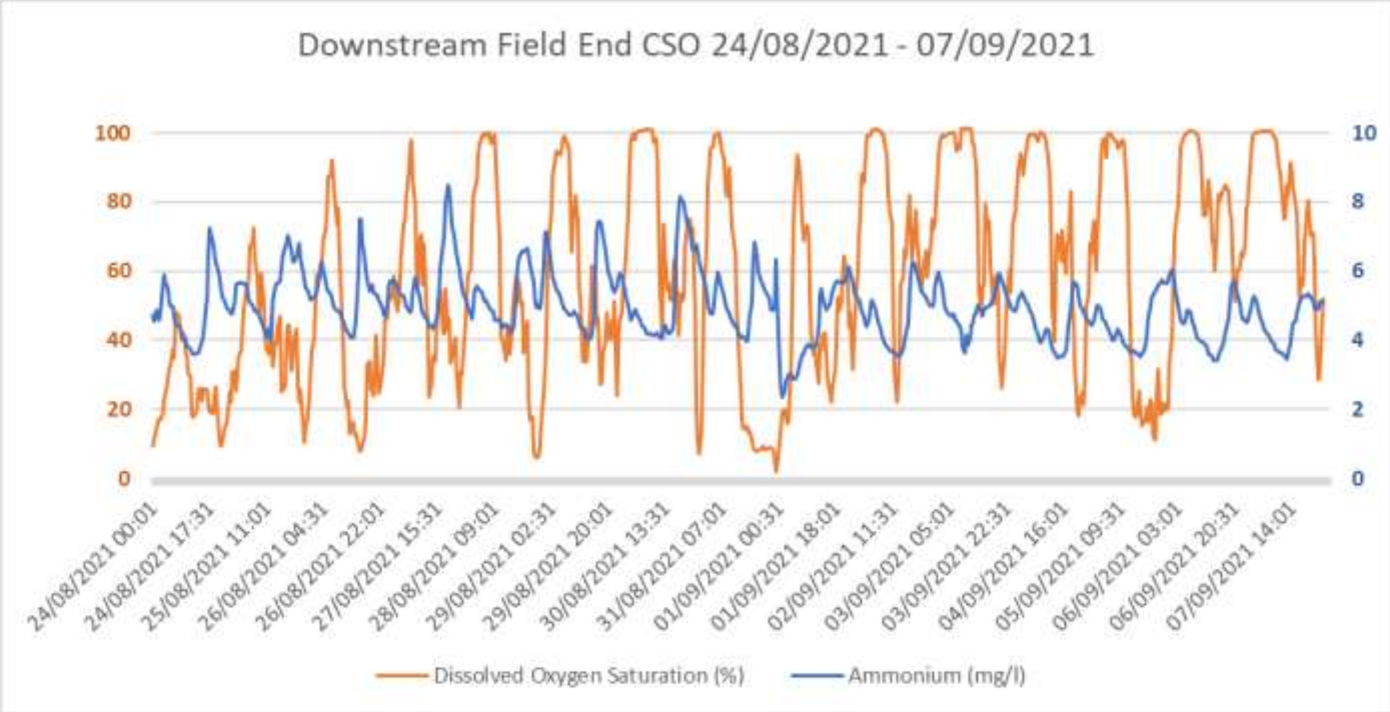


Figure 17: Map of sample sites referenced in Table 3.

Further sonde data for the period of the pollution incident are shown in Figure 18.



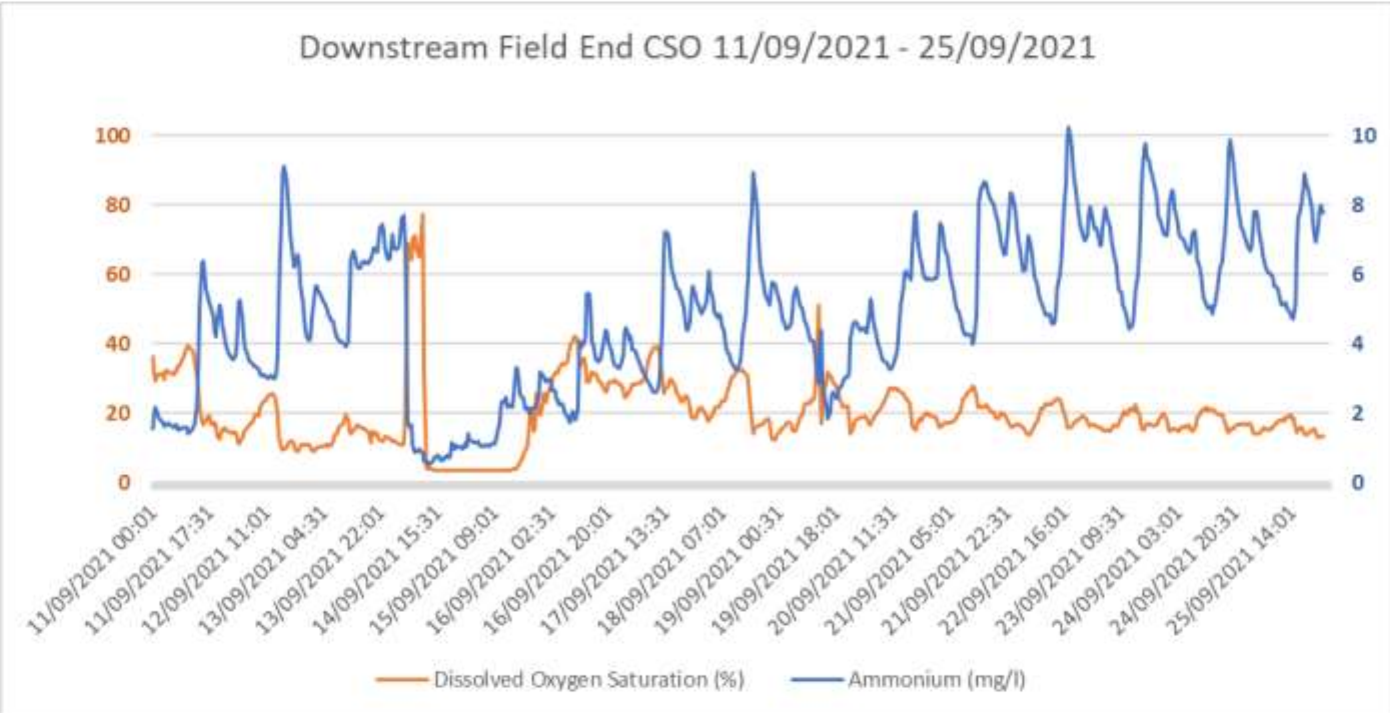


Figure 18: charts comparing ammonium and DO data from the sonde Downstream of Field End CSO before and after Thames Water cleared a blockage at Paddock Road, Ruislip on 10/09/2021

Rainfall on the 14/09/2021 and 19/09/2021 caused the increase in DO and drop in ammonium seen in Figure 18, making it difficult to compare directly. However, the recurrence of diurnal ammonium concentrations peaking above 8 mg/l during dry weather, along with DO at 20% indicates that the blockage cleared on 10/09/2021 was not the sole source of pollution in the Yeading Brook East.

For this reason, the sonde at Site 6, Downstream of the Field End CSO, has been retained in place beyond the end of this initial monitoring period.

Conclusions

Water Quality

- Rainfall events highlight issues typical of urban river catchments. 'First flush' events appear, from DO and ammonium data, to be more acute after extended dry periods and multiple diffuse sources of pollutants are elevating BOD, causing impoverished oxygen regimes, particularly in the upper catchment.
- Inputs of ammonium in and around the Field End Road Culvert should be considered a live, ongoing pollution event.

The use of sondes

- Ion selective sensors are helpful in identifying trends in ammonium over long time periods but do not provide accurate ammonium concentration data.
- Dissolved oxygen sensors provide an accurate measure of DO which can be used as a general indictor of river condition.
- Continuous monitoring using multiple sensors is costly and not all sensors are equally accurate or precise. As such it should only be used after careful consideration that it will provide the data needed for a particular investigation. It has been most effective at recording how water quality changes following rain events in the catchment and for discovering and keeping in view the ongoing pollution problem downstream of the CSO in the Yeading Brook East.

Recommended actions to improve water quality

Listed here are some of the ways we can alter the catchment to help improve river water quality. They are listed so that we can bear them in mind when considering the water quality impact of SWC proposals. The primary action needed to protect the Crane, and other rivers, is to stop pollution at source. This is a huge societal challenge however involving a much-needed step change in the way we address a multitude of problem areas including, but not limited to: urban design, regulation and use of hazardous chemicals, road design and management, and investment and management of sewer infrastructure, particularly into measures that prevent sewage flooding into rivers via the surface water drainage network in areas of dual drainage.

Secondary measures that will help improve water quality include:

Improve the hydrogeomorphology of the river

Interventions that renaturalise the channel – particularly actions that reconnect the riparian zone with the main channel - see page 26 of Angela Gurnel's Smarter Water Catchment funded report (Gurnell and Shuker,2021) encourage natural ecosystem processes such as the processing of nitrogen, phosphorus and carbon. In addition to water quality befits there is a well-established link between the extent of intact riparian vegetation and macroinvertebrate species richness.

Daylight the river

Macrophytes, which trap organic material and take up nutrients, will only grow in river reaches where sunlight is able to reach the river**.** In many reaches of the river, largely as a result of disconnection from the riparian zone and flood plain, dense tree cover has developed which casts the river into shade. Angela

Gurnell outlines a number of reaches where reducing over-shading to increasing light to the banks is recommended (Gurnell and Shuker 2021).

Wetlands

The Crane catchment, as with all urban catchments, have developed in a way that promotes rapid surface water runoff from the surrounding land. High peak flows and reduced baseflows is a characteristic effect of urbanisation on rivers and streams (Bernhardt *et al.* 2007). Pollutants bound with solids are carried with surface water run off directly into flashy rivers. Therefore, slowing the flow and thereby capturing polluted sediment, is an important step to flattening the hydrograph and improving water quality. Wetlands can have a significant role in this. If designed and maintained correctly, through natural processes, they reduce the most damaging impact of inputs of BOD and other pollutants. Revitt *et al.* (1999) stress the need for regular removal of contaminated sediment, and for design to incorporate an overflow channel so as to minimise resuspension of solids during high flows. This paper presents compelling evidence on the efficacy of wetlands in removing diffuse urban pollution. Ian Russell of Enfield Local Authority (Russell *et al.* 2021) suggests that a good rule of thumb is that wetland systems surface area should be between 1 to 5% of the catchment area. Multiple wetlands can be scaled to fit the available open space at multiple locations within a catchment.

Access, visibility and structured citizen science programmes

Outfall Safari data shows the most polluting outfalls are generally found in reaches hidden away from public view, by sensitively encouraging public access and community ownership along the river we will build the opportunity for more community monitoring and pollution reporting in the catchment.

Data storage

A sharepoint has been created which will be the central storage point for project deliverables and outputs including reports, GIS layers, presentations and anything else related to the Smarter Water Catchment Programme. All data that are used to inform baseline assessments and/or future milestones will be stored here. Pending legal agreement, all relevant project partners will have access to the sharepoint.

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Appendix 1: Additional charts

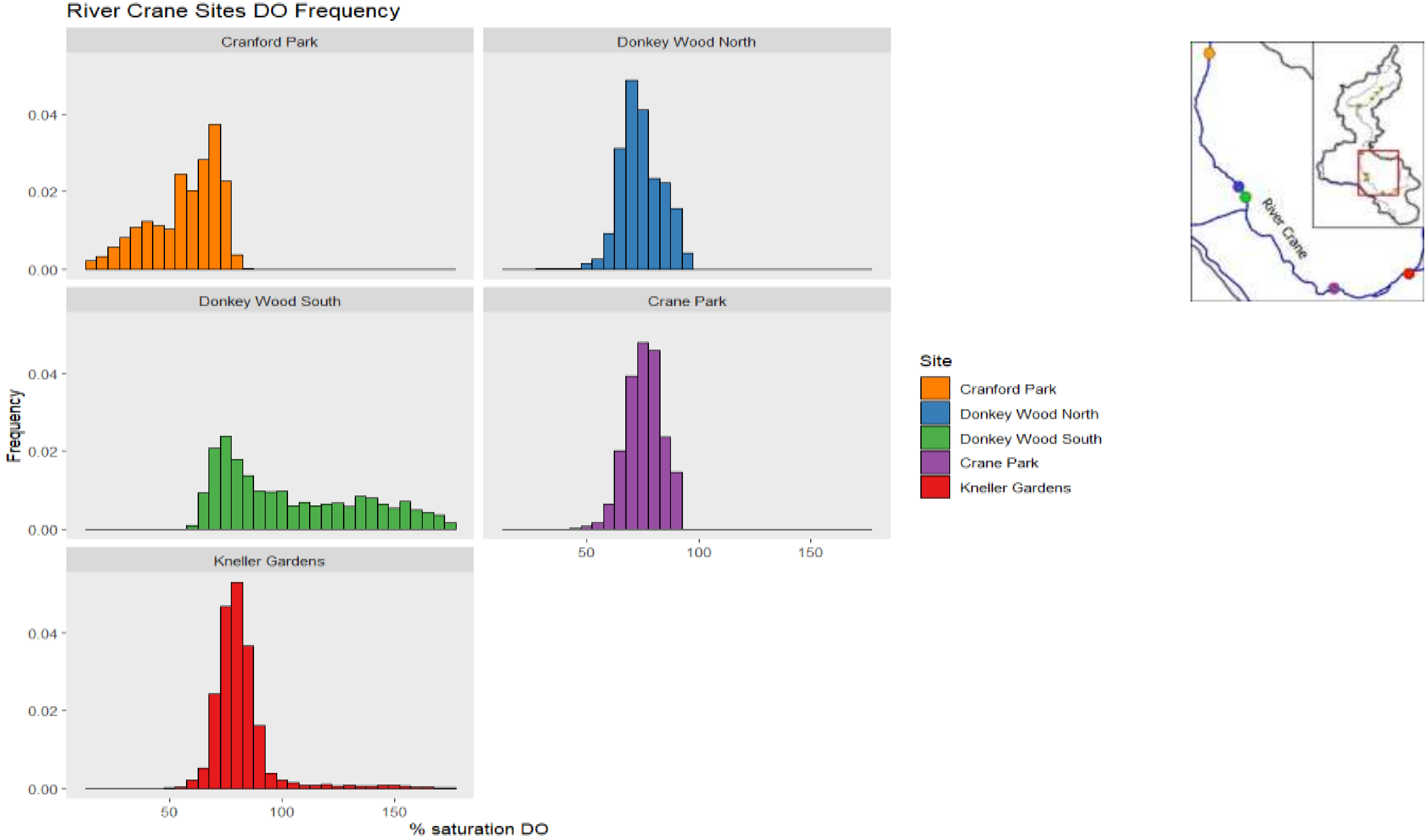

Figure 19: Relative frequency of DO % saturation. The area of each bar in the histogram represents the percentage of time DO % saturation was within the indicated range.

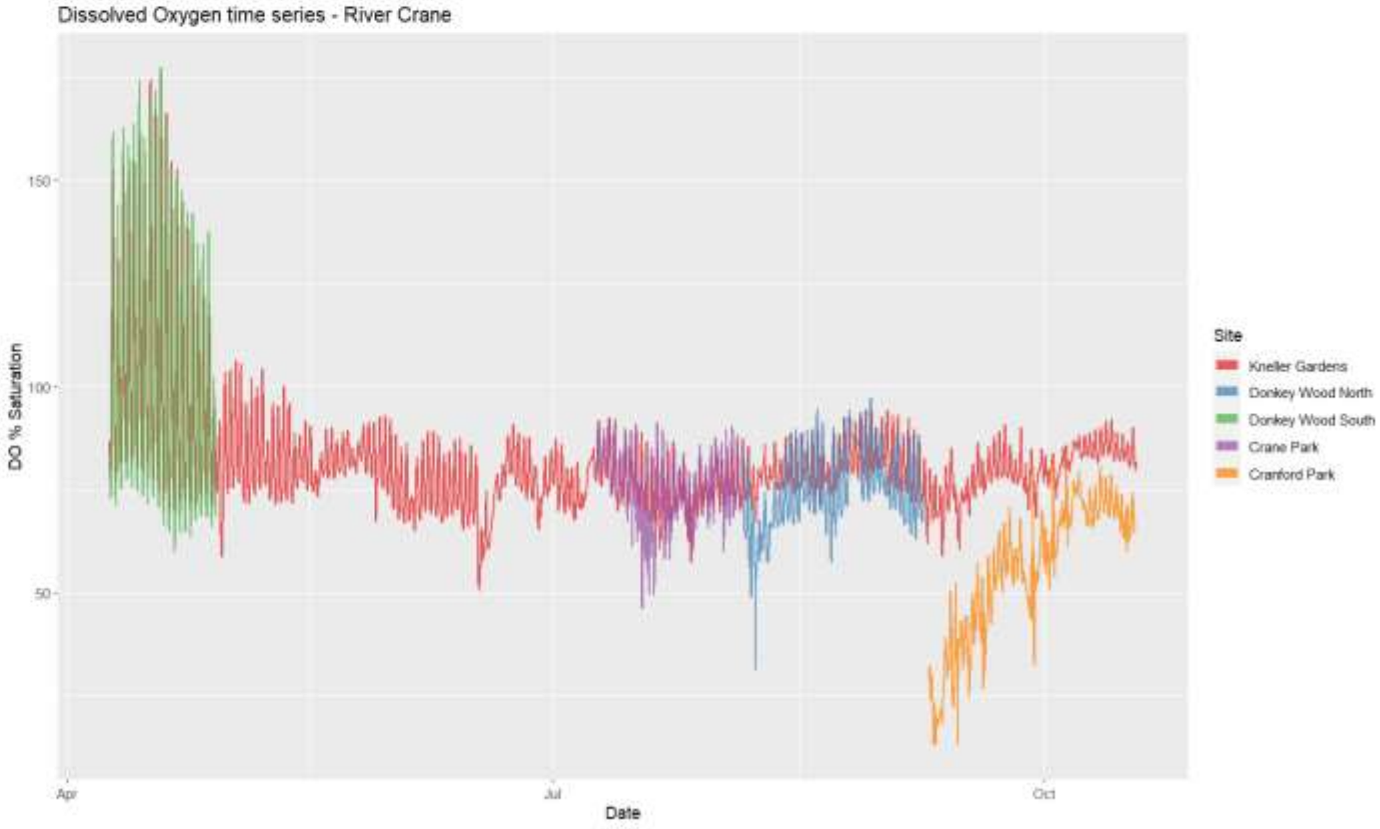

Figure 20: Time series of DO % saturation for all River Crane sonde locations.

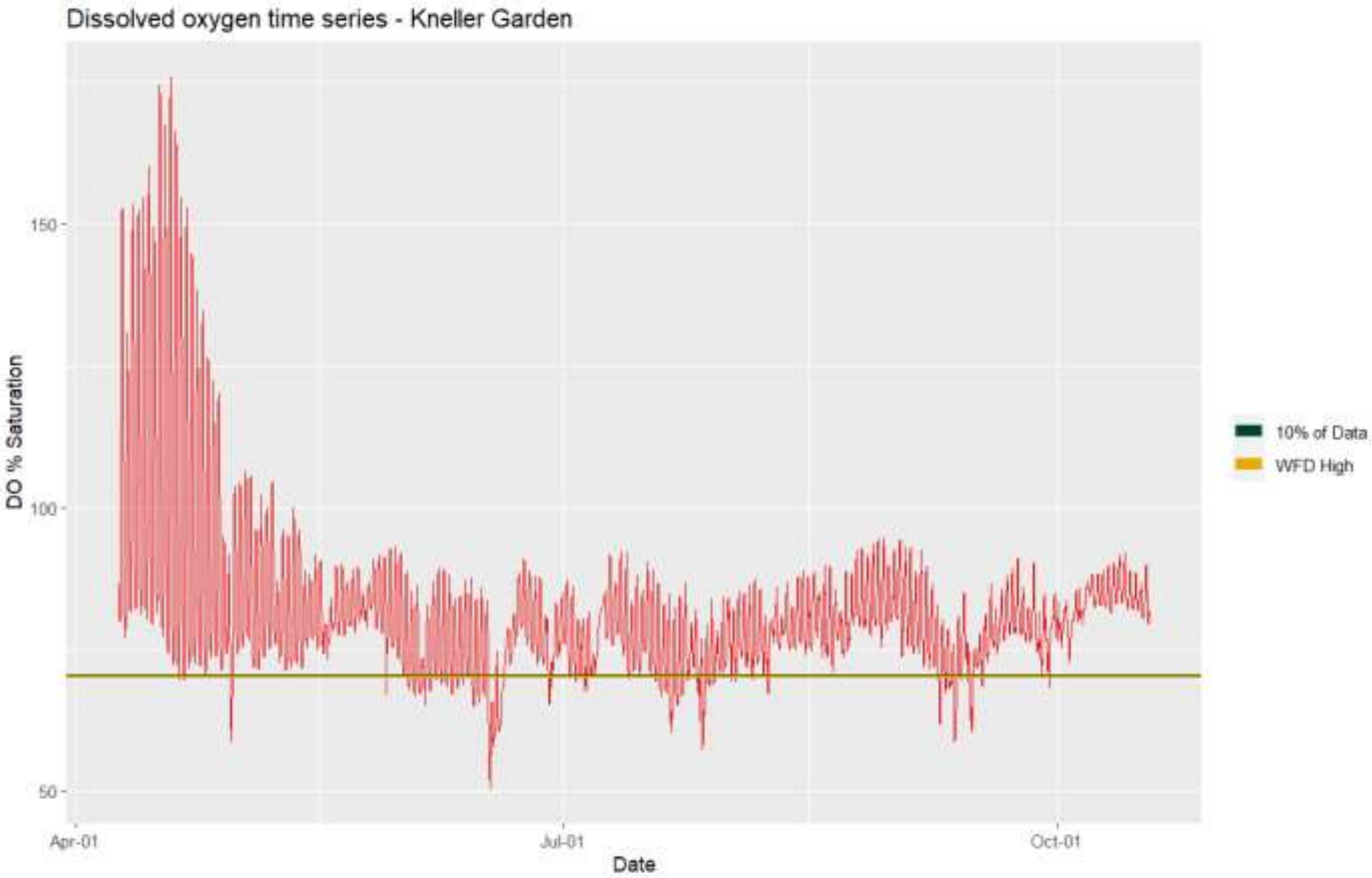

Figure 21: Time series of DO % saturation for Kneller Garden sonde, with 10th percentile marked in comparison to the nearest WFD standard.

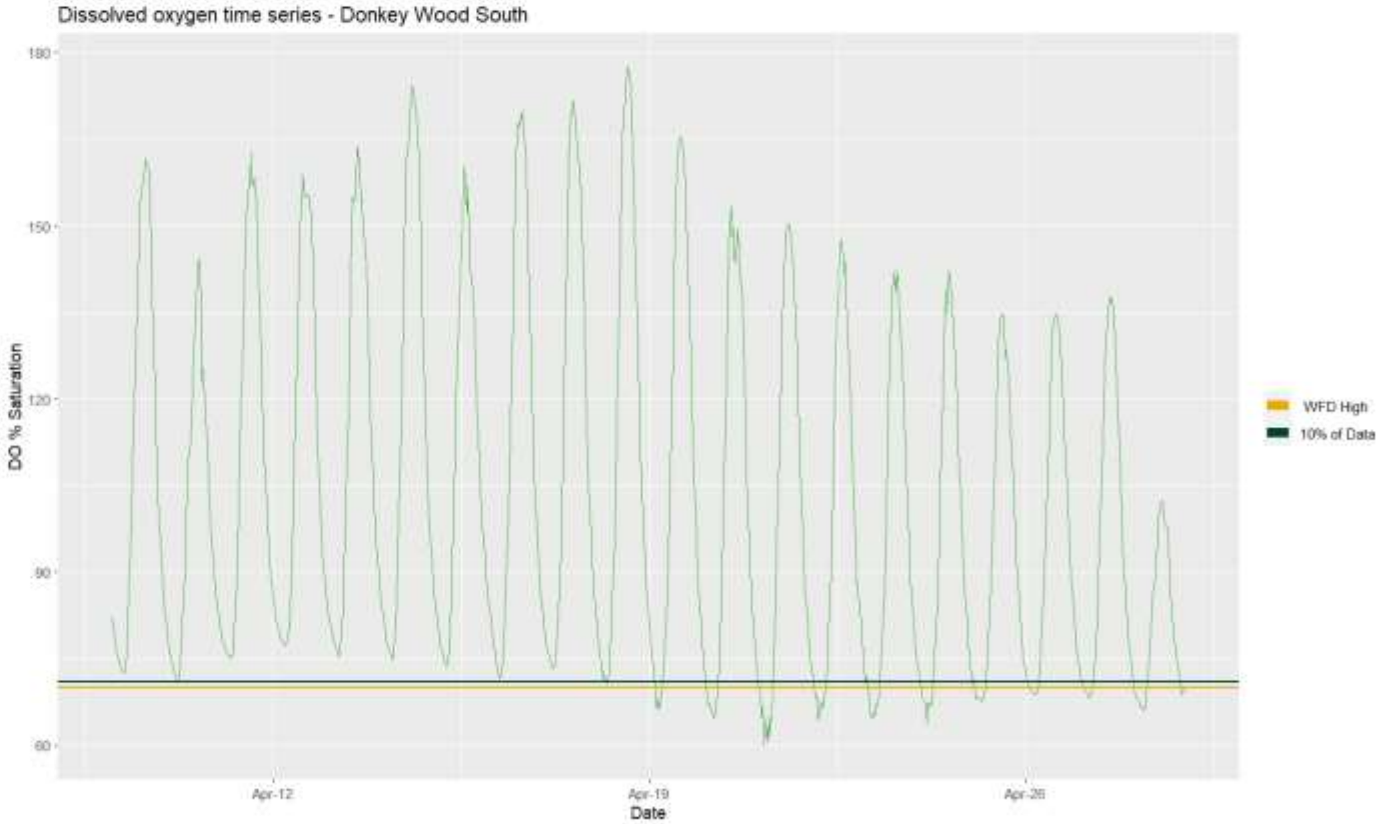

Figure 22: Time series of DO % saturation for Donkey Wood Upstream sonde, with 10th percentile marked in comparison to the nearest WFD standard.

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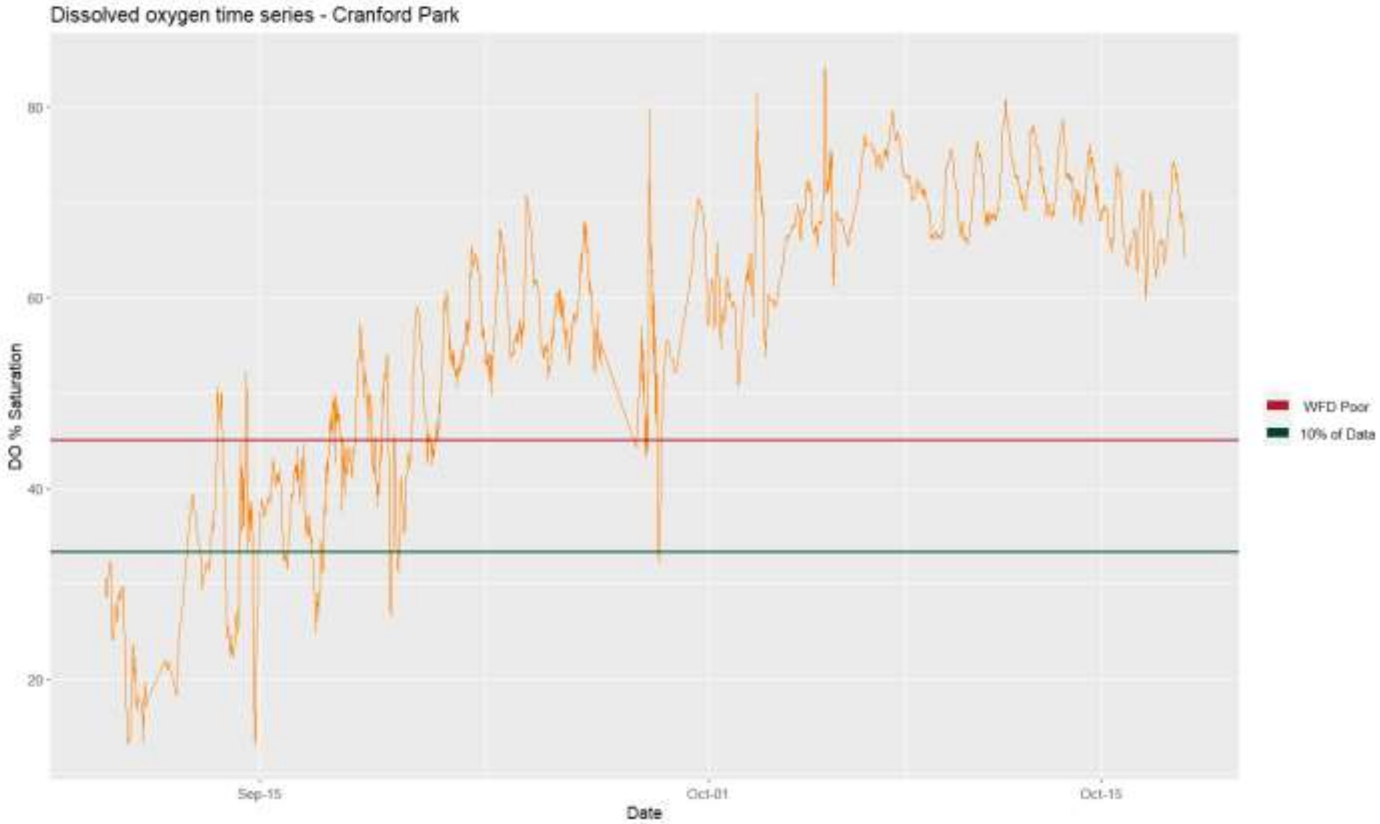
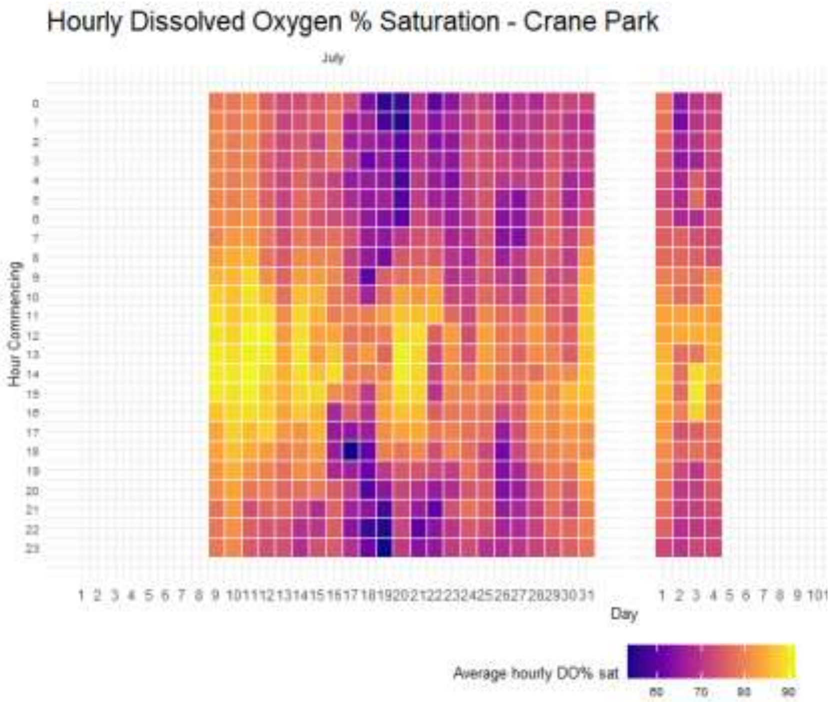
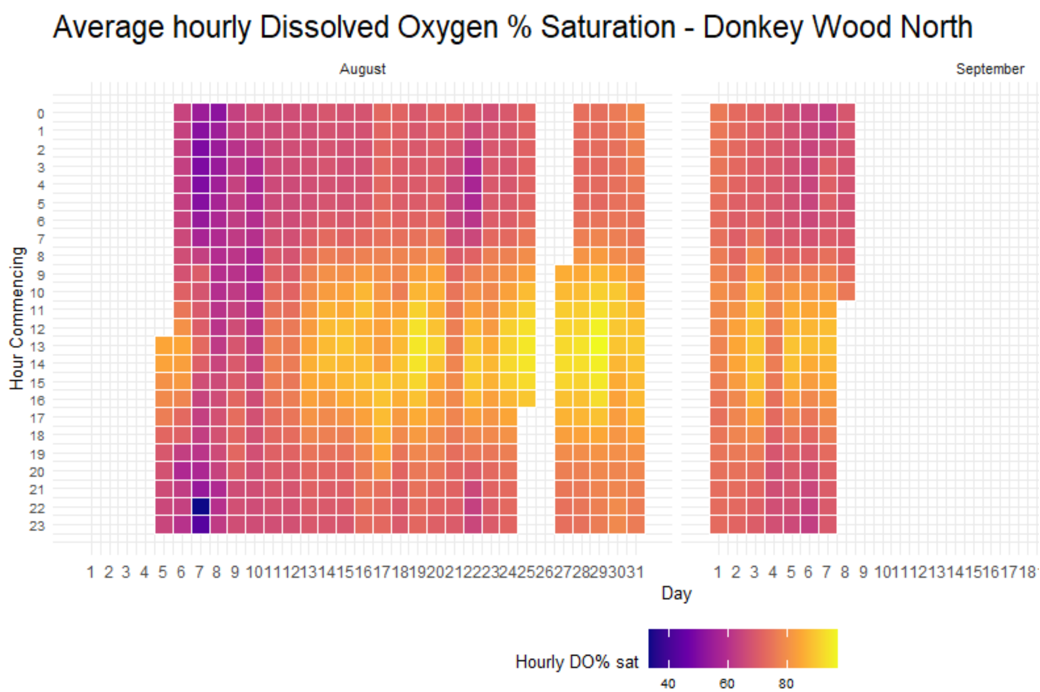


Figure 23: Time series of DO % saturation for Cranford Park sonde, with 10th percentile marked in comparison to the nearest WFD standards.

River Crane DO heatmaps





Figures 24 & 25: Heatmaps showing hourly average DO % saturation at Crane Park and Donkey Wood North. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

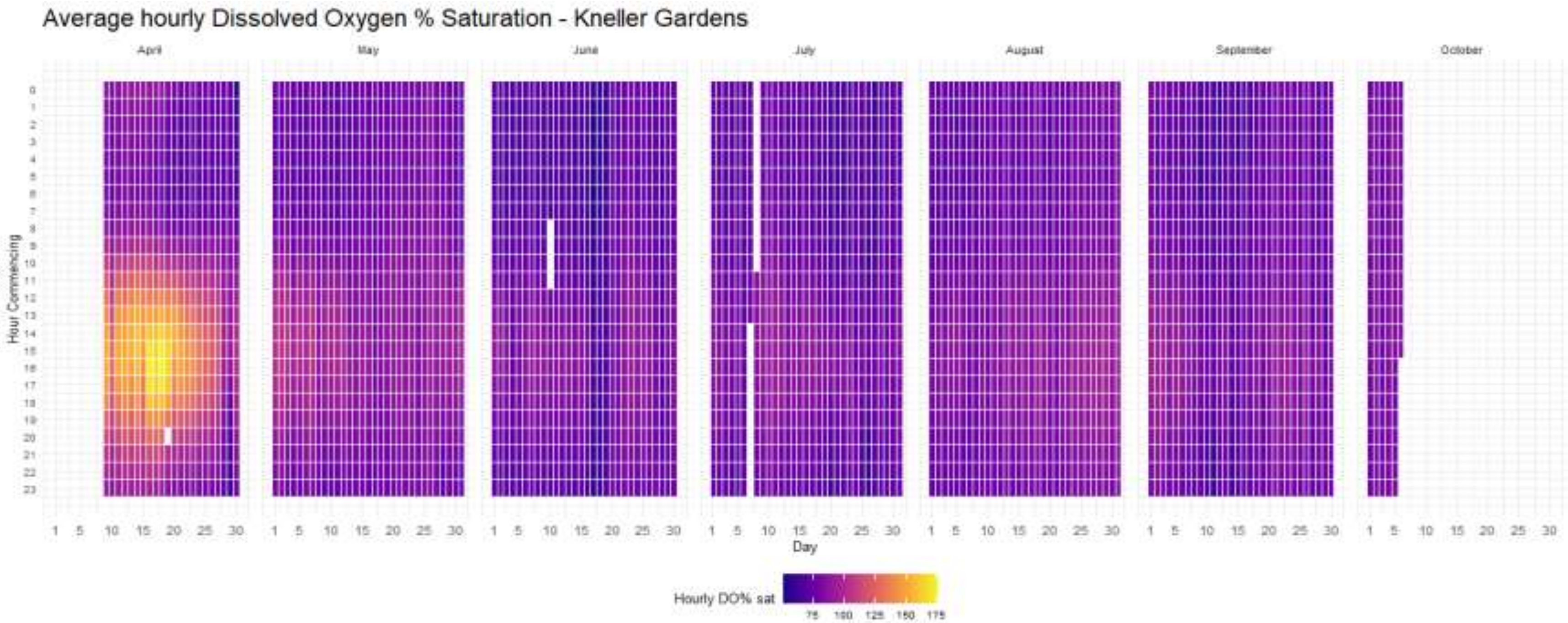


Figure 26: Heatmaps showing hourly average DO % saturation at Kneller Gardens. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

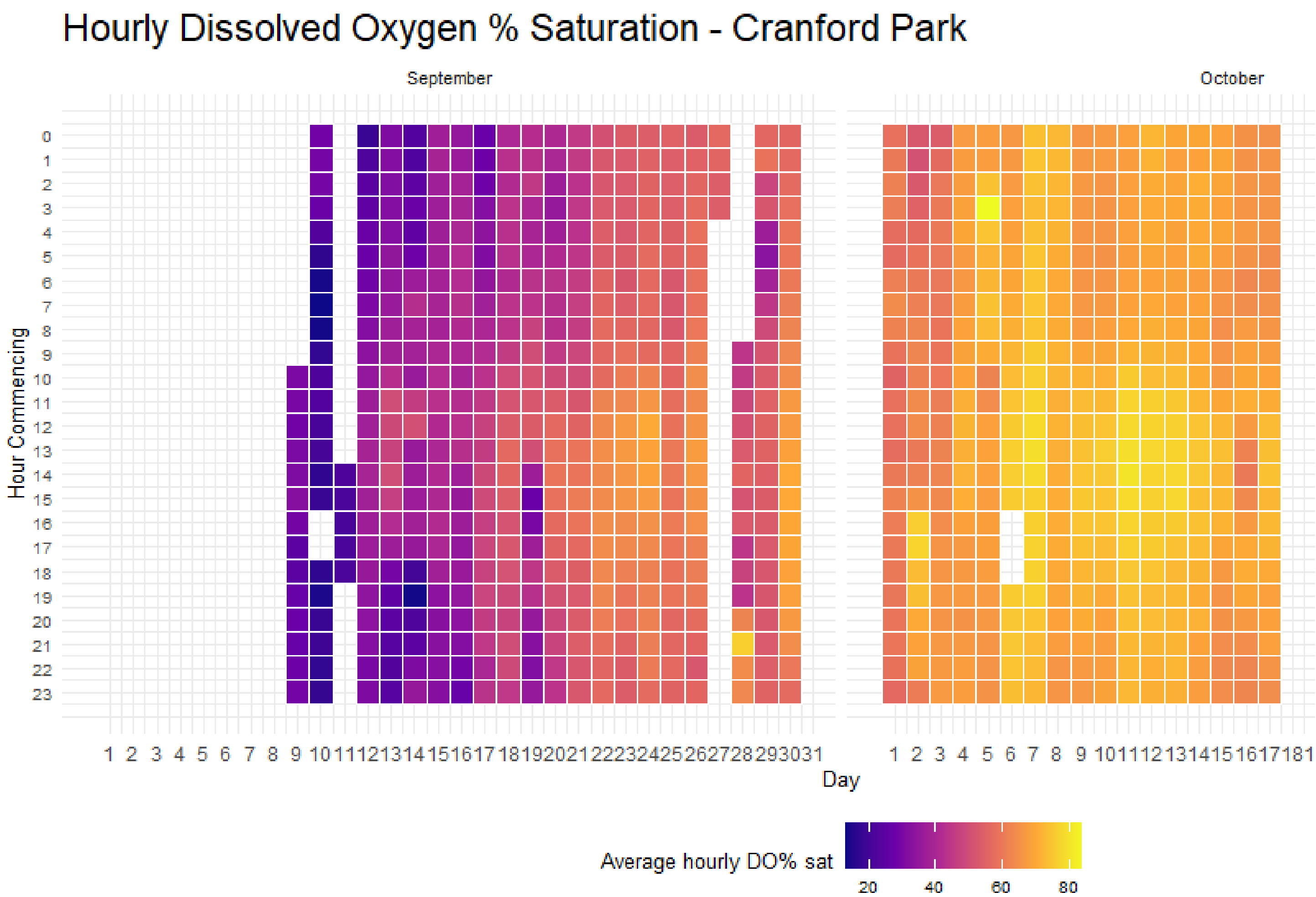
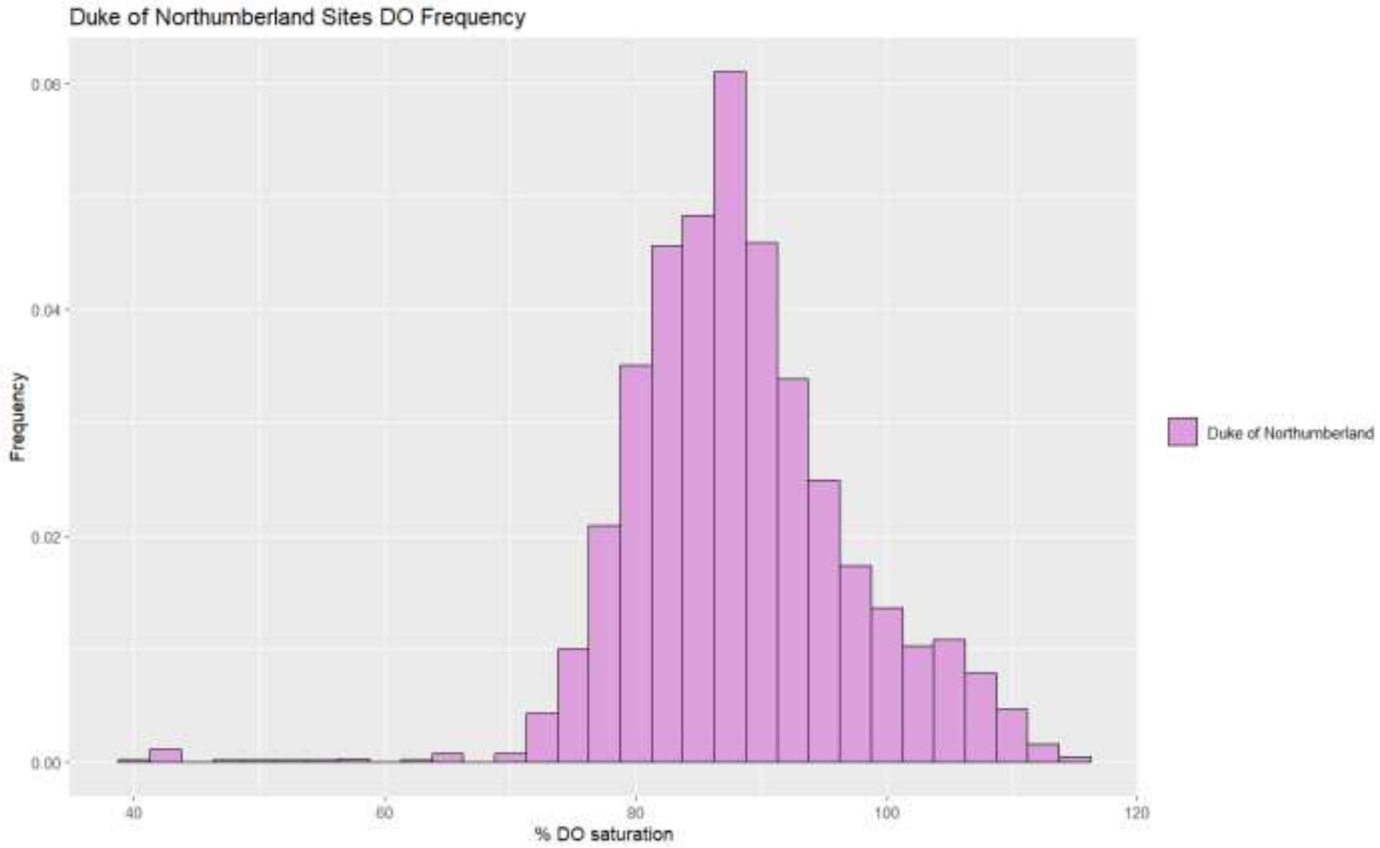


Figure 27: Heatmaps showing hourly average DO % saturation at Cranford Park. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

Dissolved Oxygen – Duke of Northumberland's River



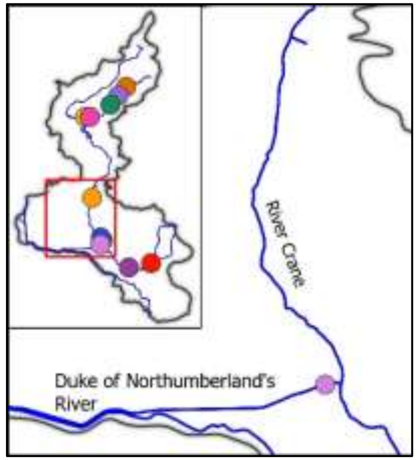


Figure 28: Relative frequency of DO % saturation. The area of each bar in the histogram represents the percentage of time DO % saturation was within the indicated range.

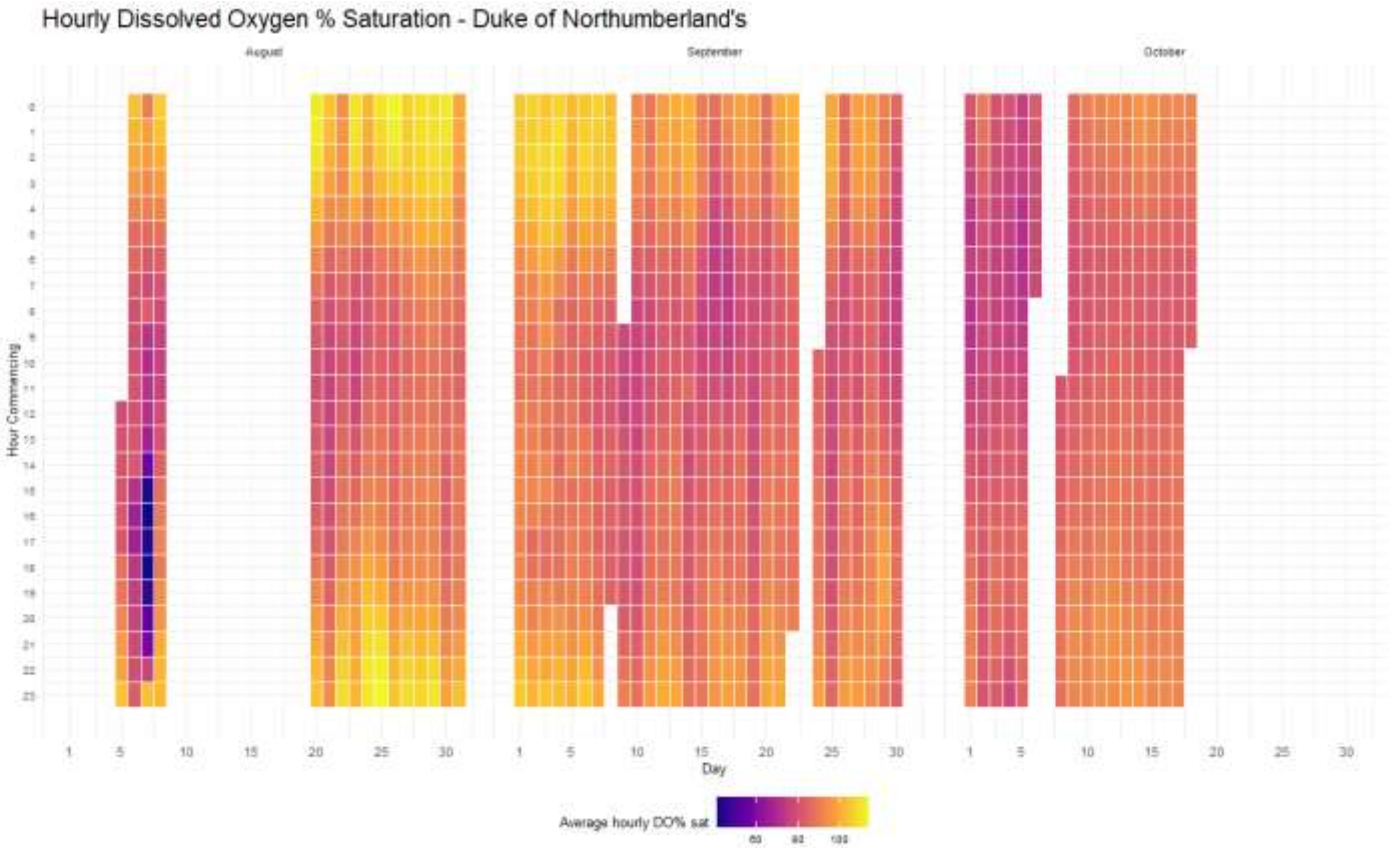


Figure 29: Heatmaps showing hourly average DO % saturation at Duke of Northumberland. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

Dissolved Oxygen – Yeading Brook east

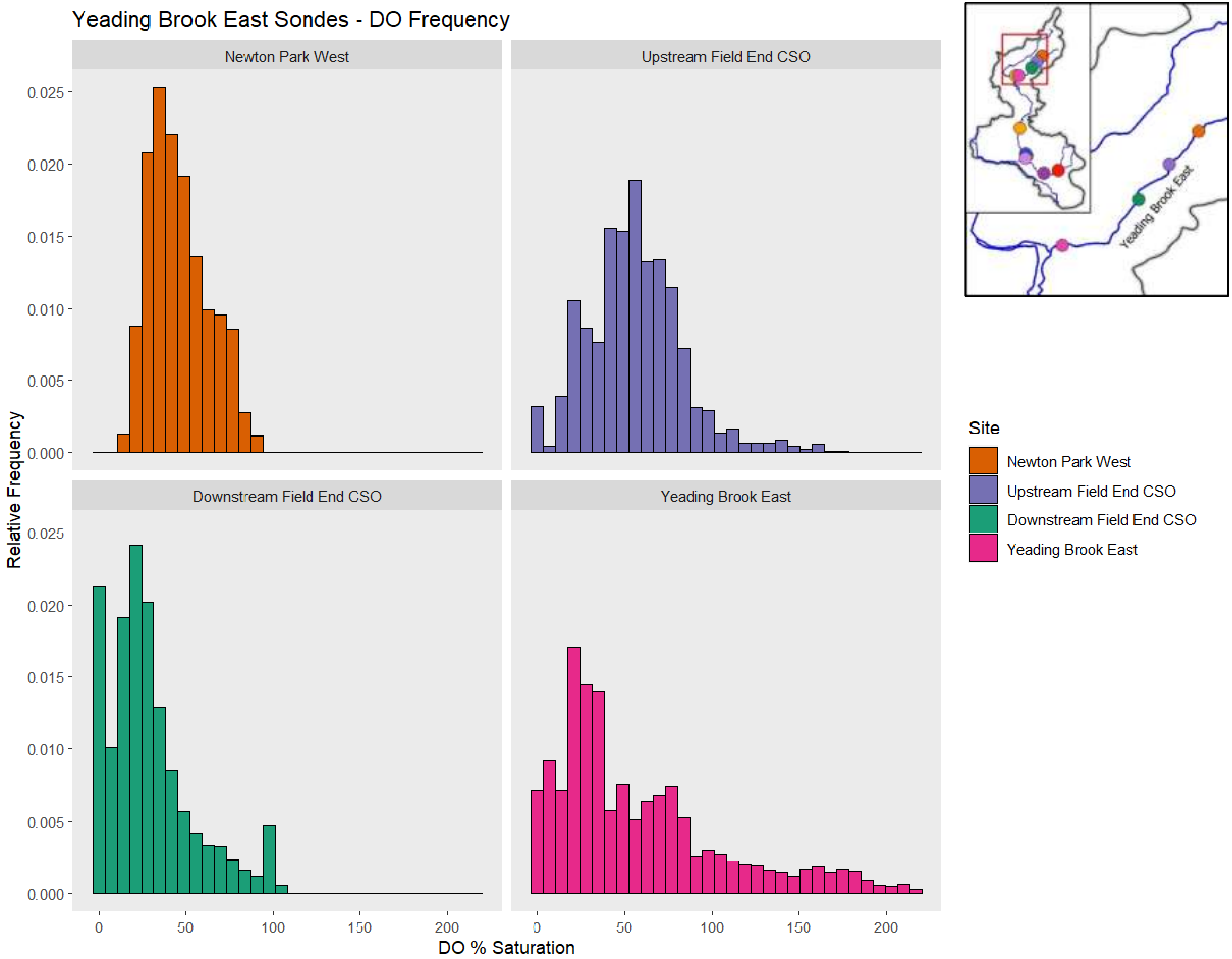

Yeading Brook East Sondes - DO Frequency
Newton Park West
Upstream Field End CSO
Downstream Field End CSO
Yeading Brook East
Relative Frequency
0.000
0.005
0.010
0.015
0.020
0.025
0
50
100
150
200
DO % Saturation
Site
Newton Park West
Upstream Field End CSO
Downstream Field End CSO
Yeading Brook East
Yeading Brook East

Figure 30. Relative frequency of DO % saturation. The area of each bar in the histogram represents the percentage of time DO % saturation was within the indicated range.

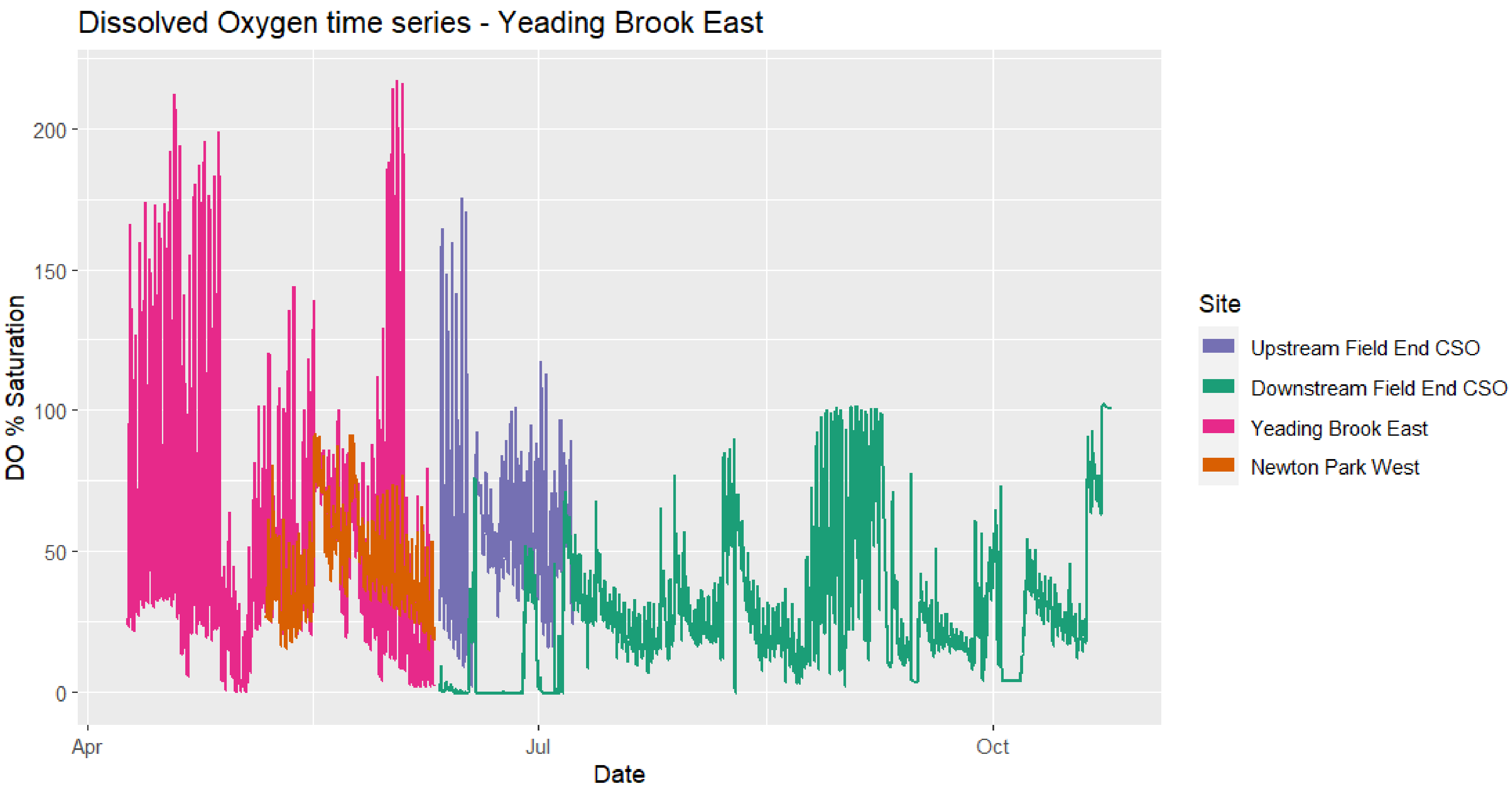


Figure 31: Time series of DO % saturation for all Yeading Brook east sonde locations.

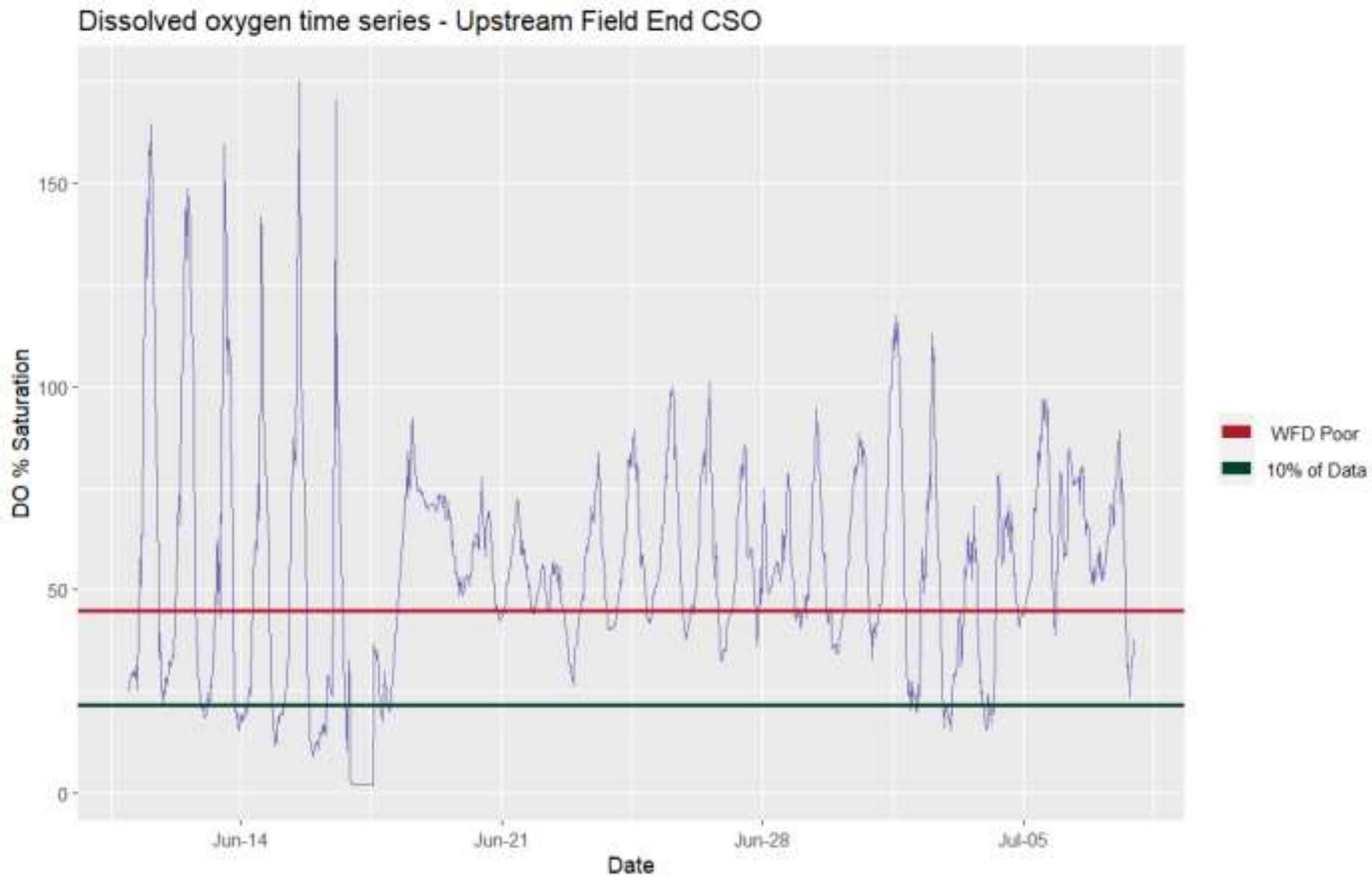


Figure 32: Time series of DO % saturation for Upstream Field End sonde, with 10th percentile marked in comparison to the nearest WFD standard.

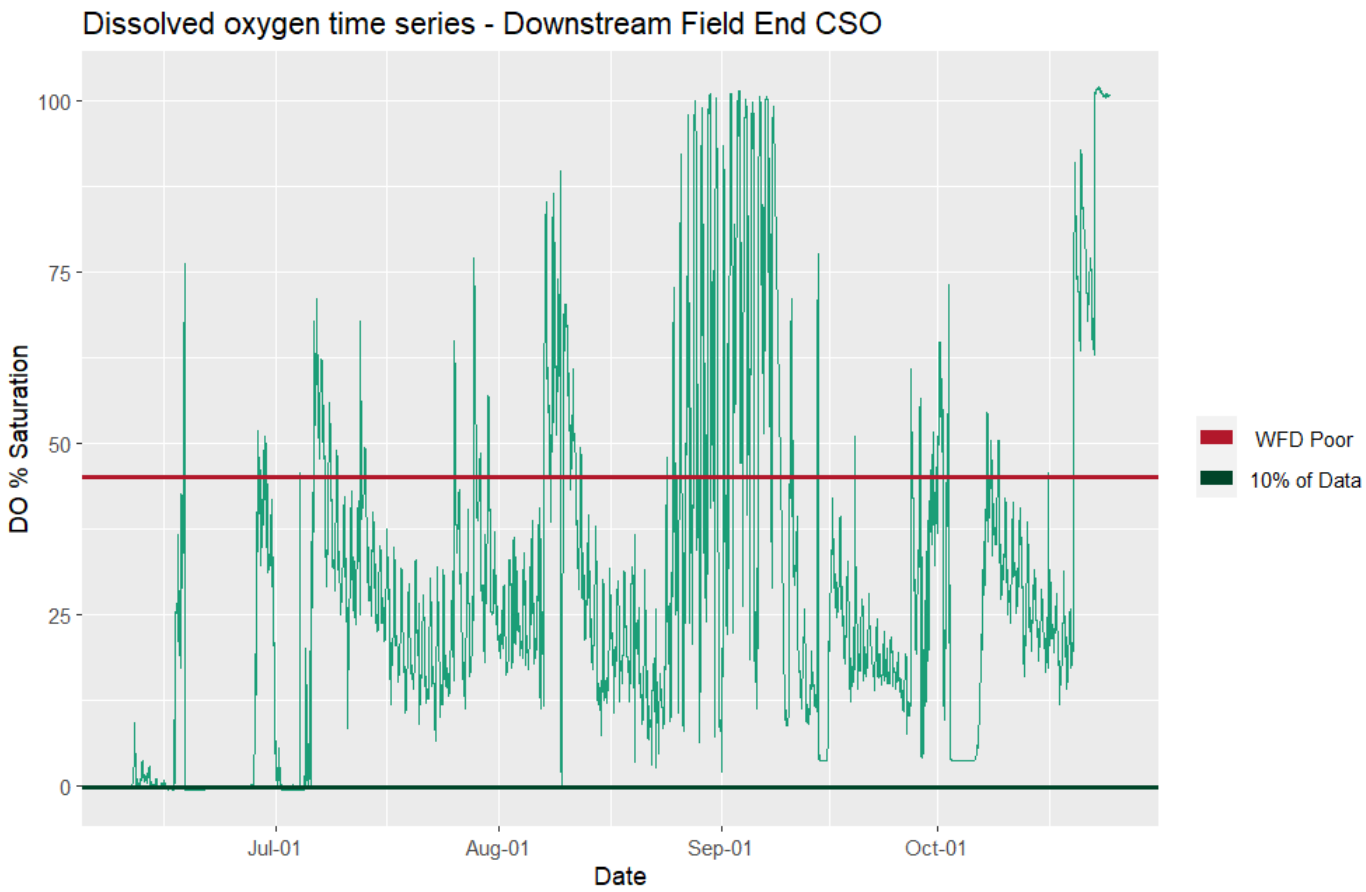


Figure 33: Time series of DO % saturation for Downstream Field End sonde, with 10th percentile marked in comparison to the nearest WFD standard.

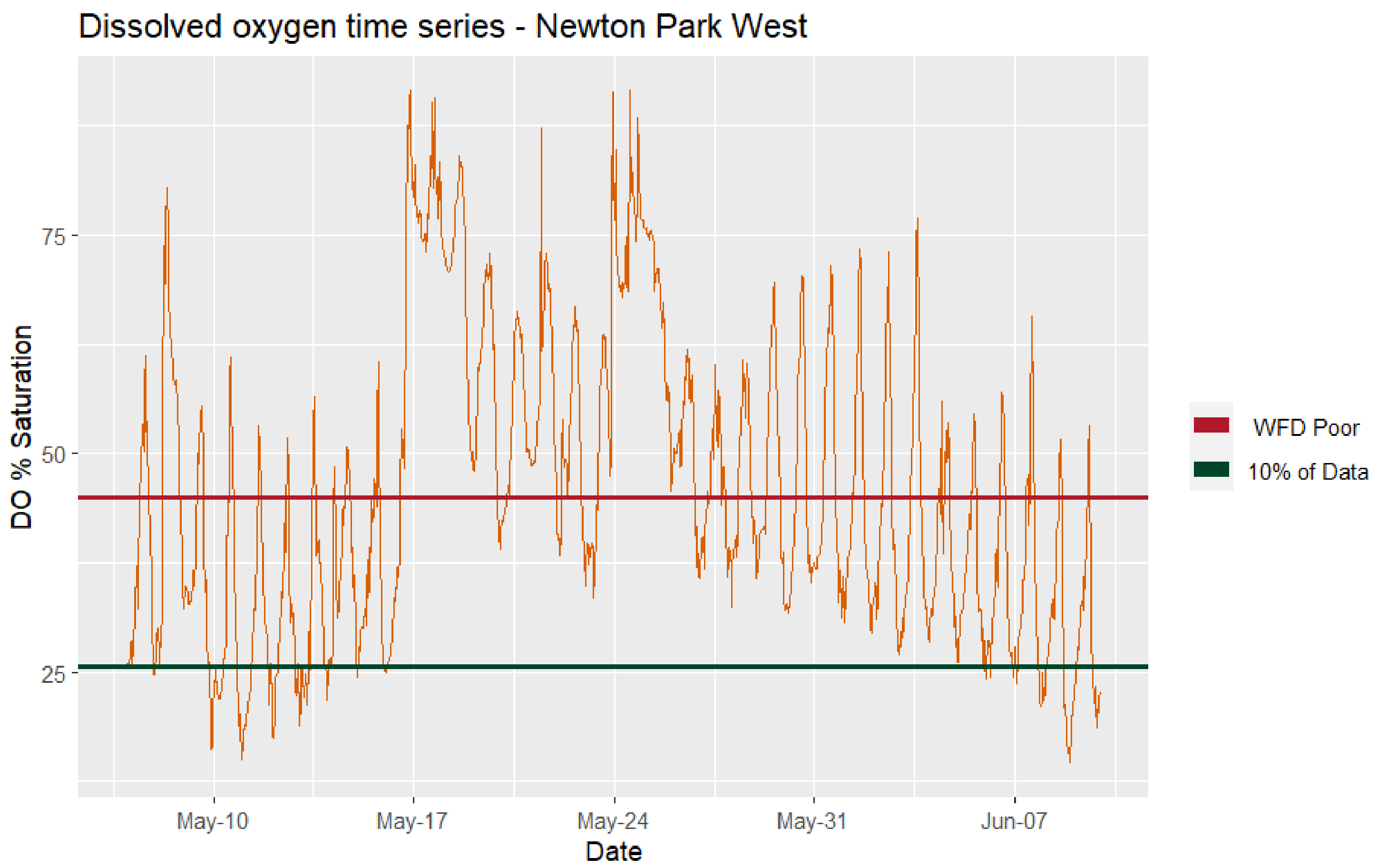


Figure 34: Time series of DO % saturation for the Newton Park West sonde, with 10th percentile marked in comparison to the nearest WFD standard.

Ammonium Heatmap – Downstream Field End CSO

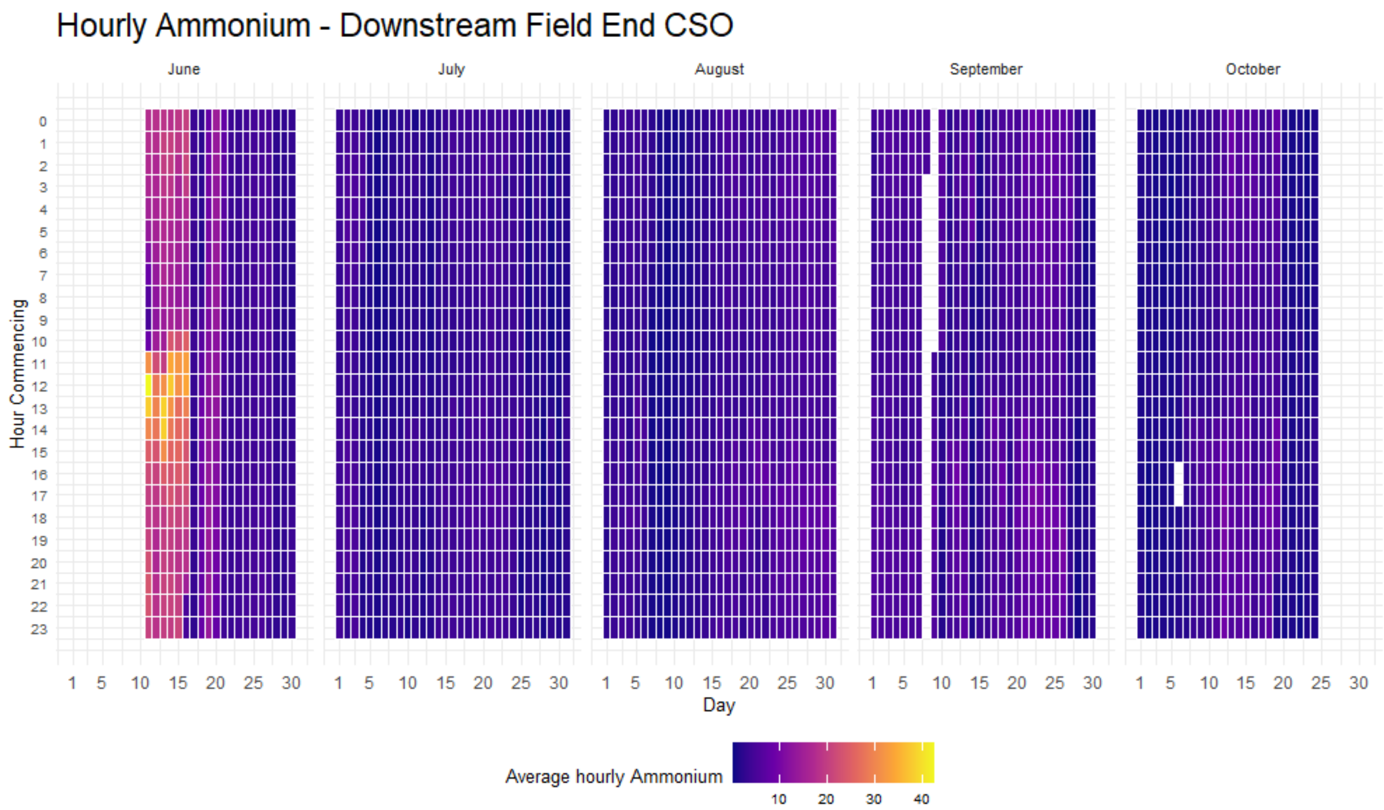


Figure 35: Heatmaps showing hourly average ammonium at Downstream Field End CSO. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

DO Heatmaps – Yeading Brook East Sites

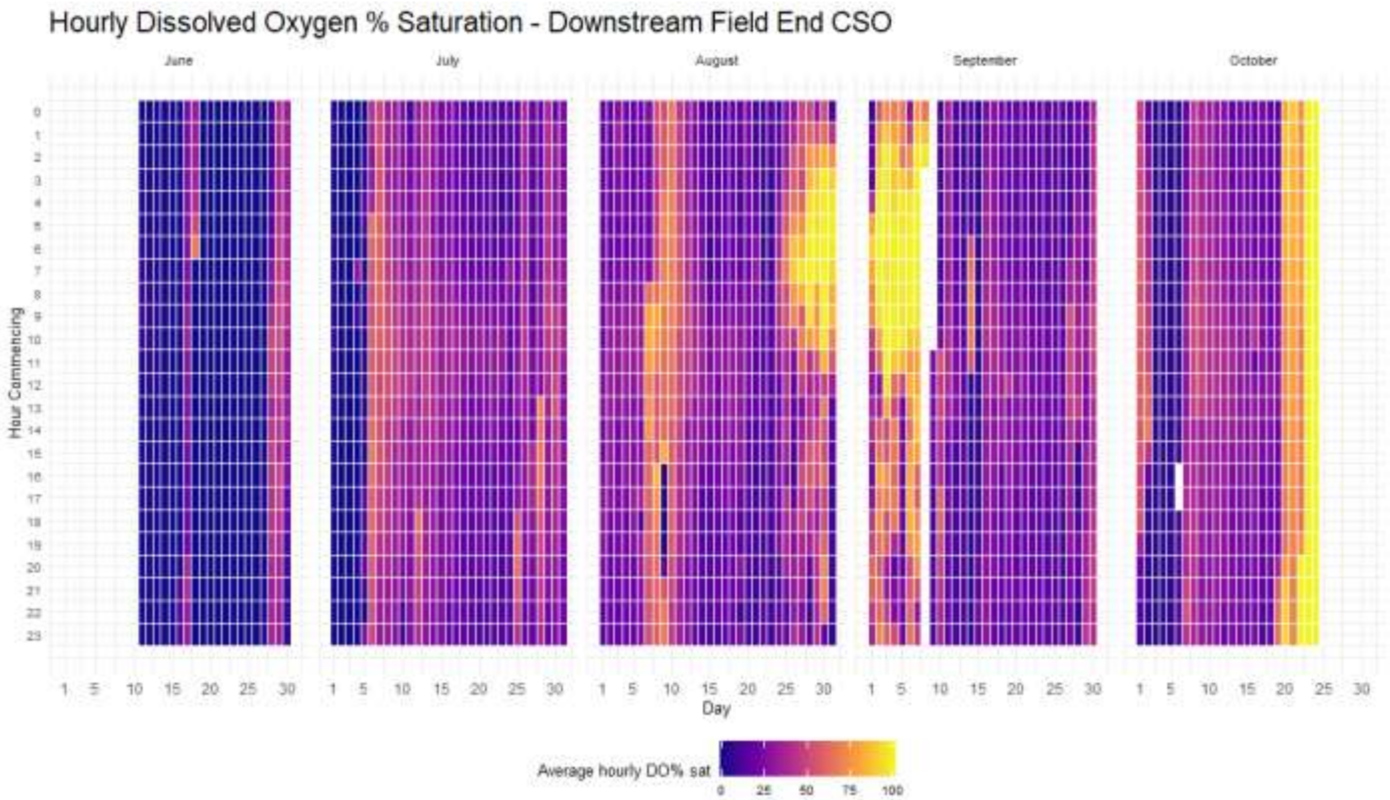
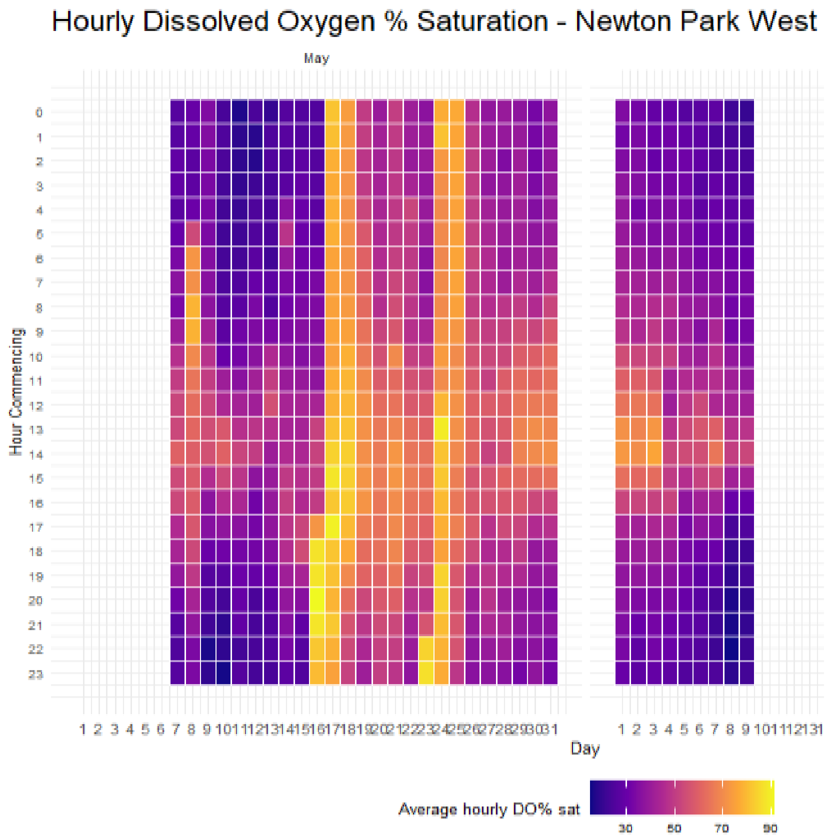
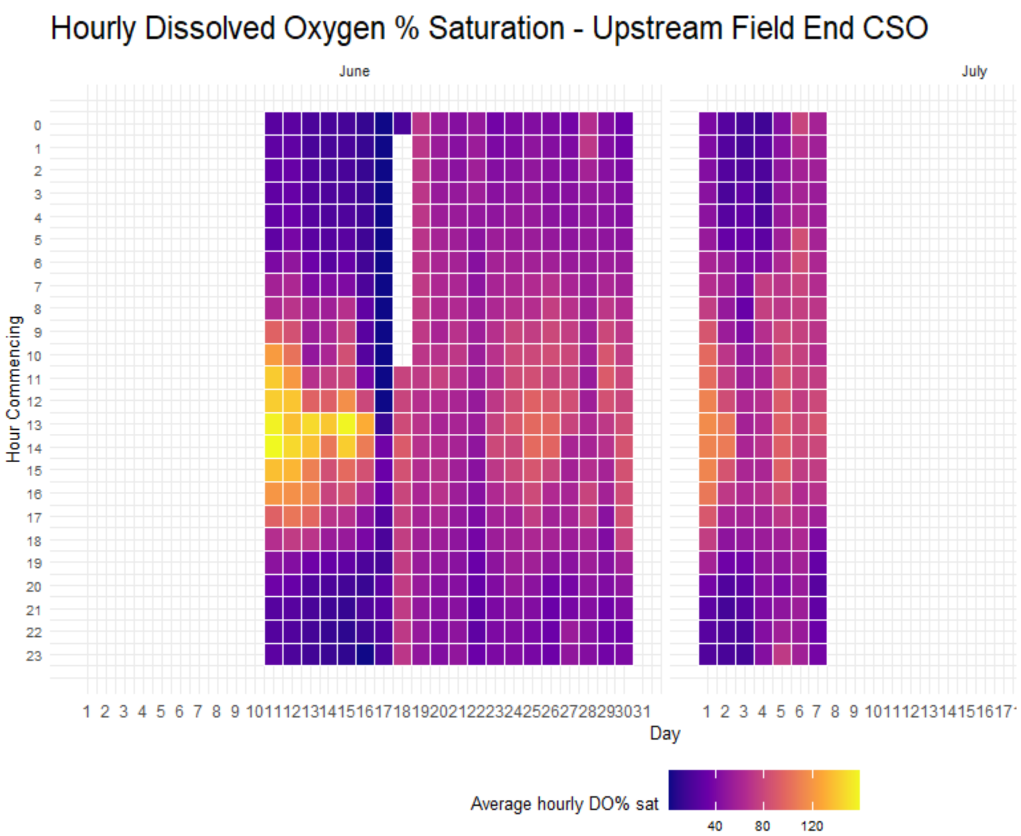


Figure 36: Heatmaps showing hourly average DO % saturation at Downstream Field End CSO. Light yellow represents high DO saturation, while darker blue represents low DO saturation.





Figures 37 & 38: Heatmaps showing hourly average DO % saturation at Newton Park West and Upstream Field End CSO. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

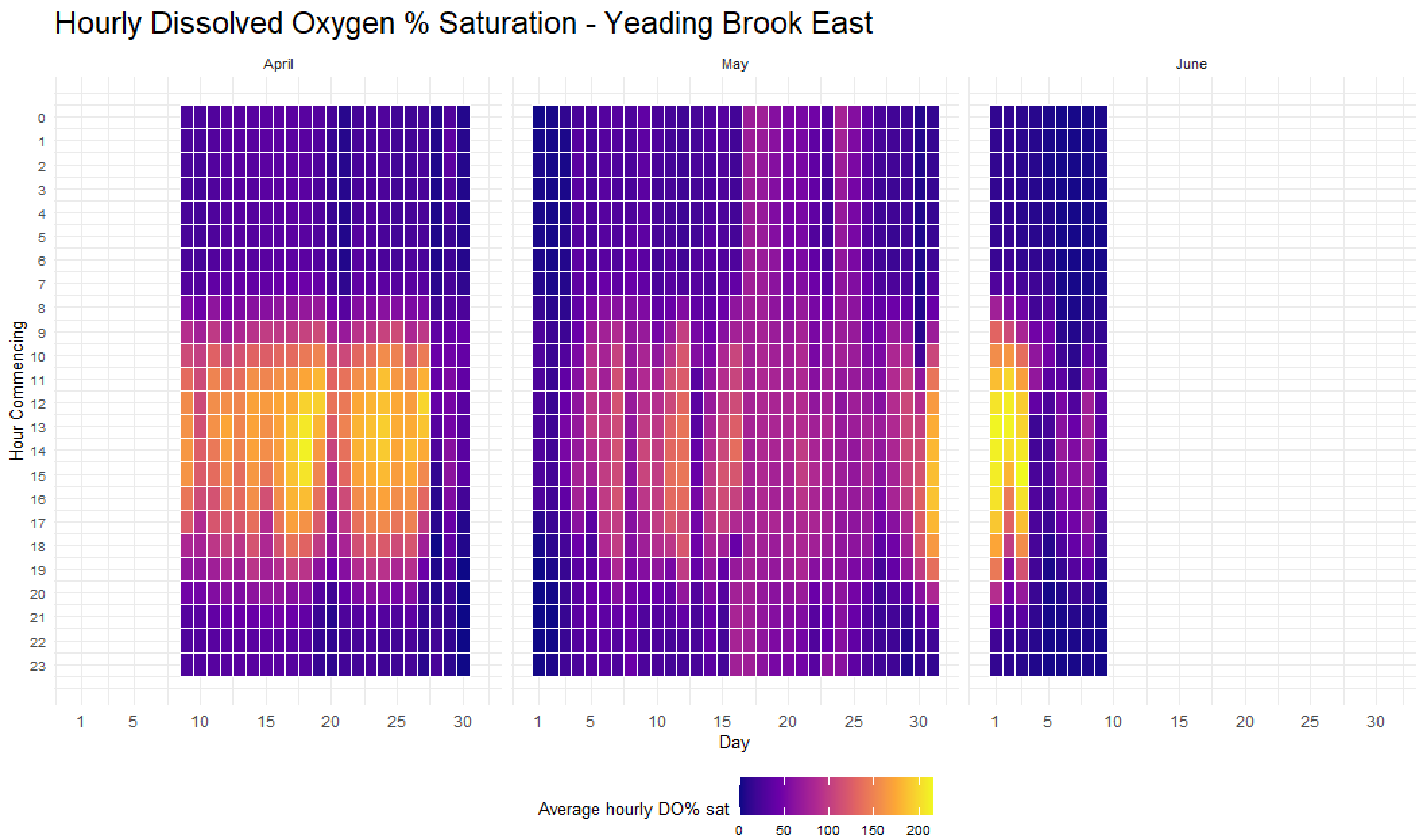
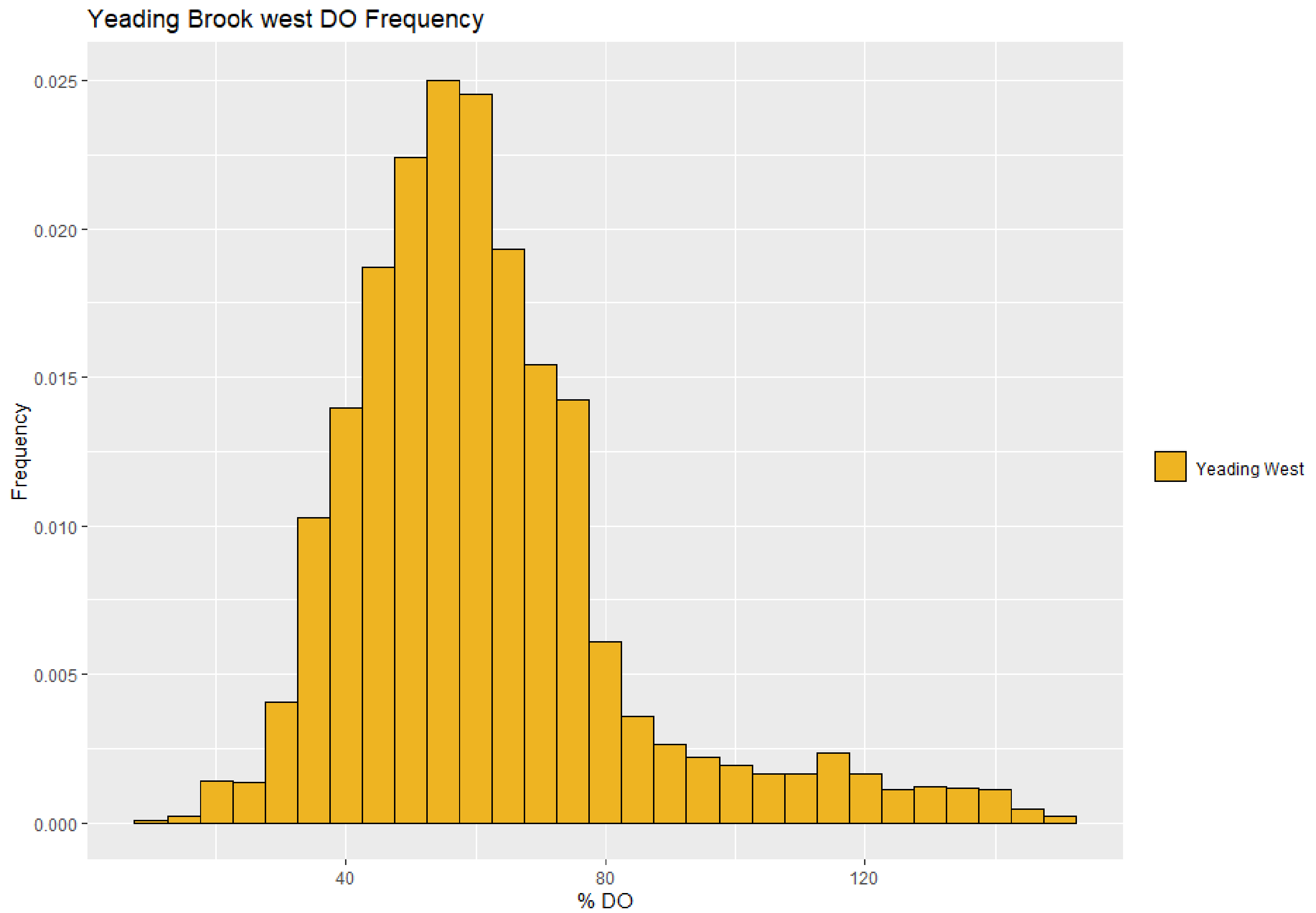


Figure 39: Heatmaps showing hourly average DO % saturation at Yeading Brook East. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

Dissolved Oxygen – Yeading Brook west



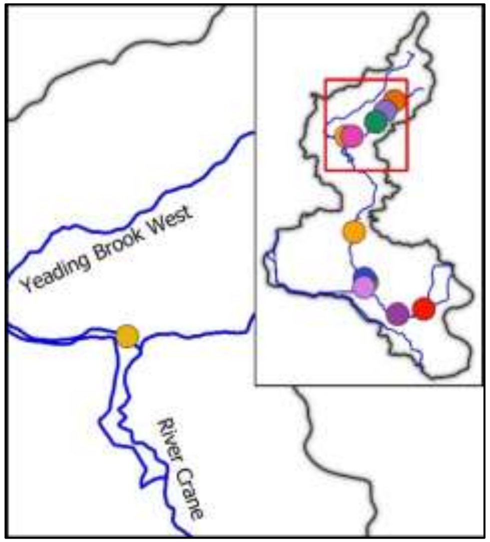
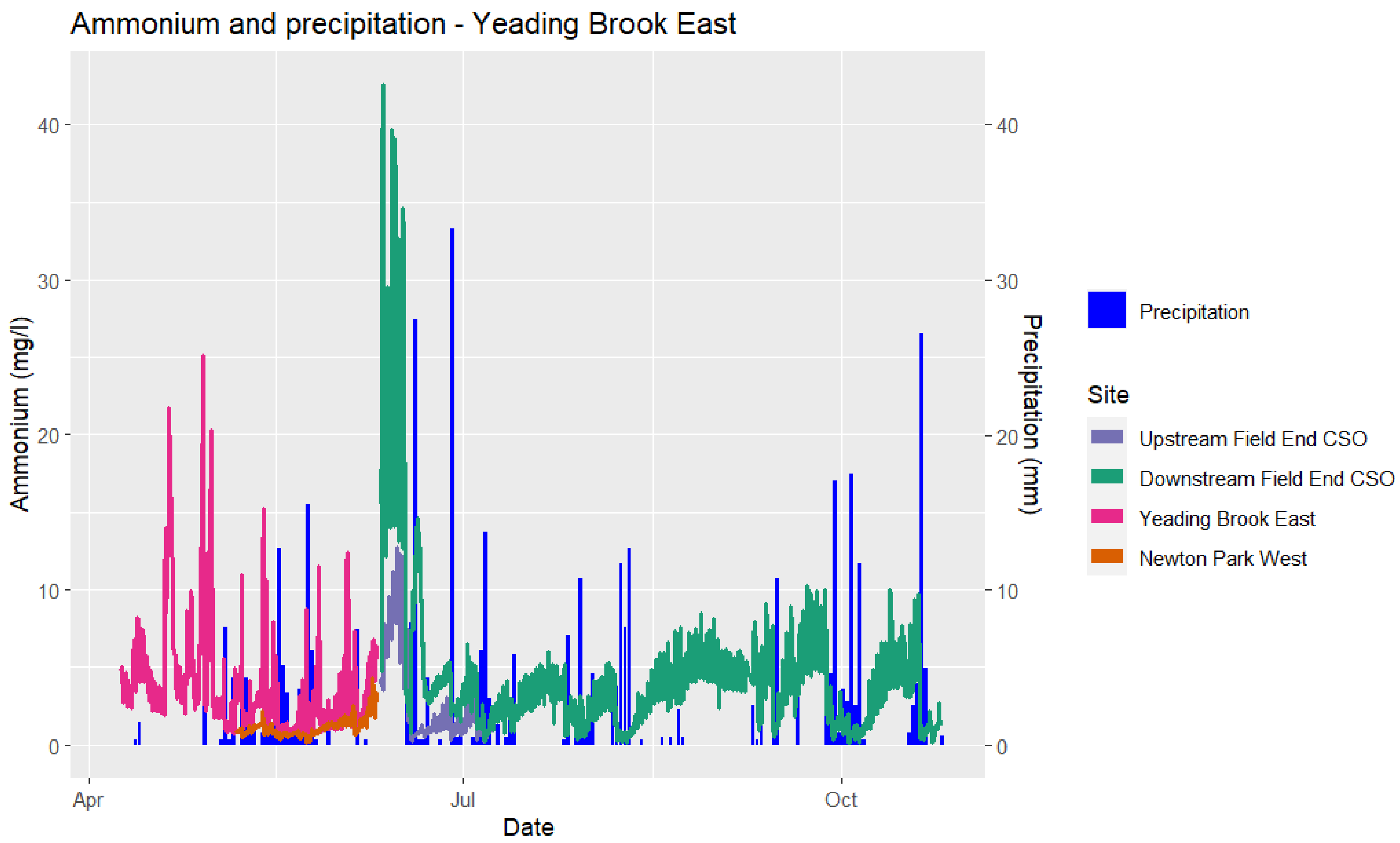


Figure 40. Relative frequency of DO % saturation. The area of each bar in the histogram represents the percentage of time DO % saturation was within the indicated range.

Figure 41: Heatmaps showing hourly average DO % saturation at Yeading Brook West. Light yellow represents high DO saturation, while darker blue represents low DO saturation.

Ammonium & Precipitation



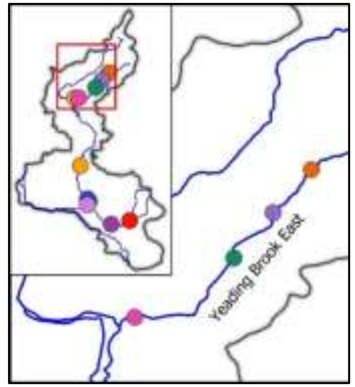
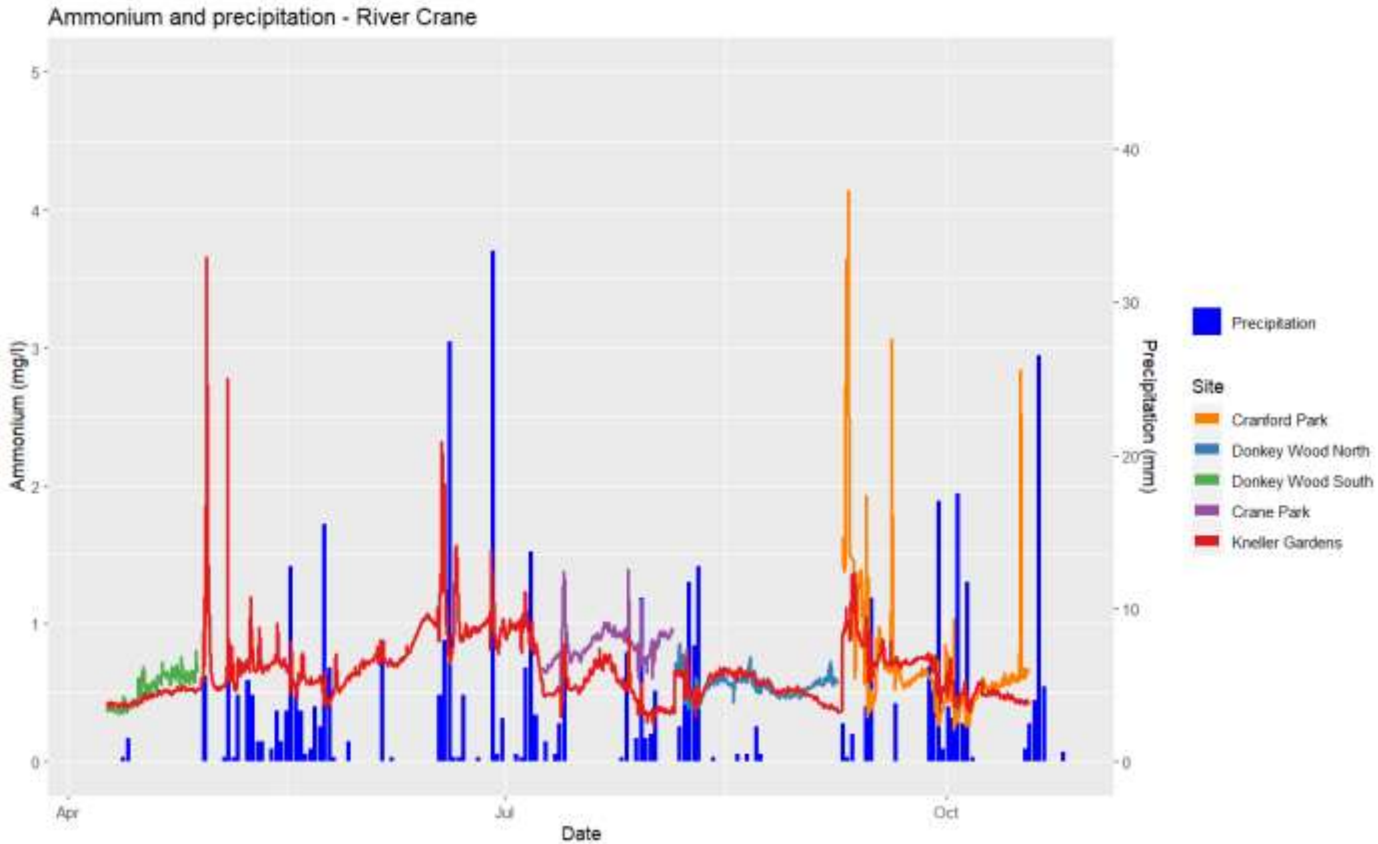


Figure 42: Ammonium time series for all Yeading Brook East sondes, along with total daily precipitation.



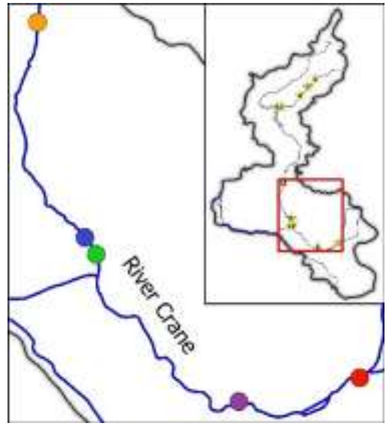
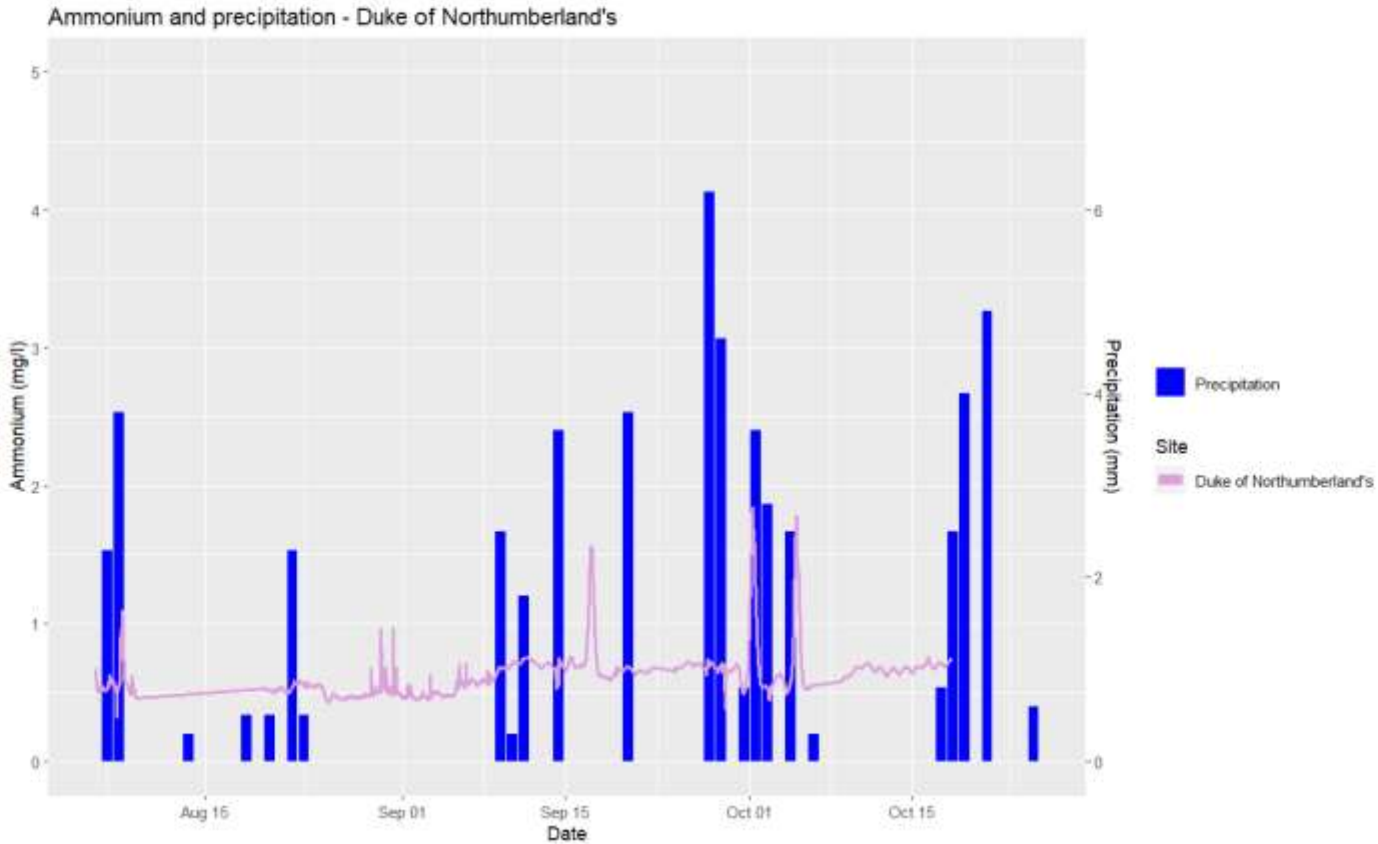


Figure 43: Ammonium time series for all River Crane sondes, along with total daily precipitation.



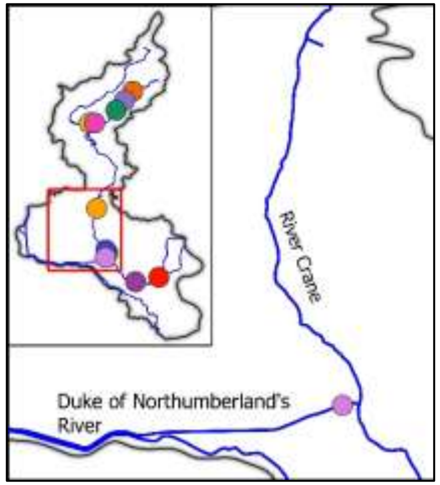
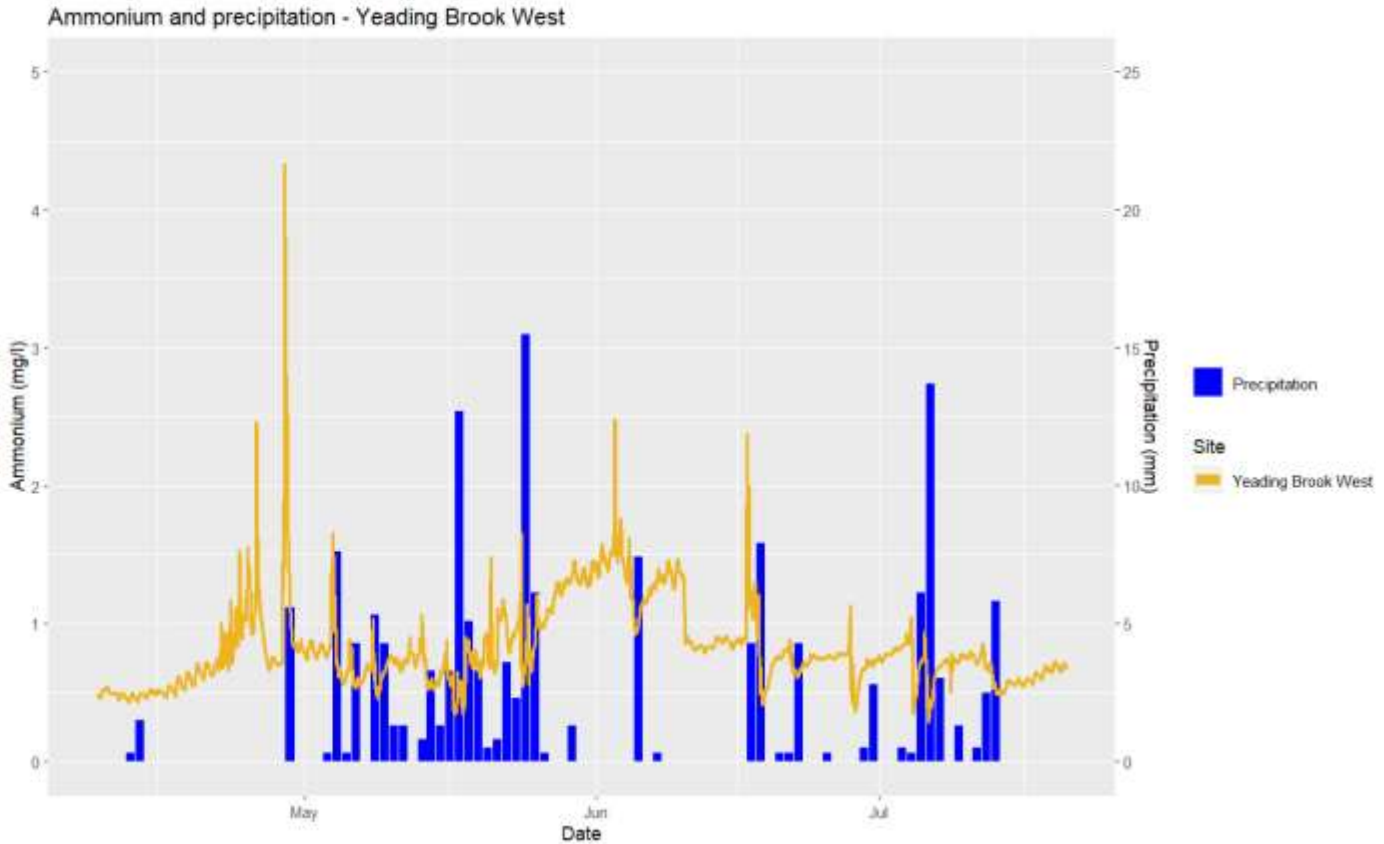


Figure 44: Ammonium time series for Duke of Northerumberland, along with total daily precipitation.



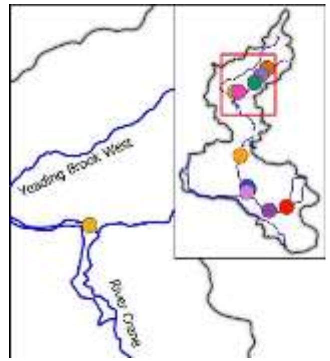


Figure 45: Ammonium time series for all Yeading Brook West, along with total daily precipitation.

Ammonium & Dissolved Oxygen during dry weather

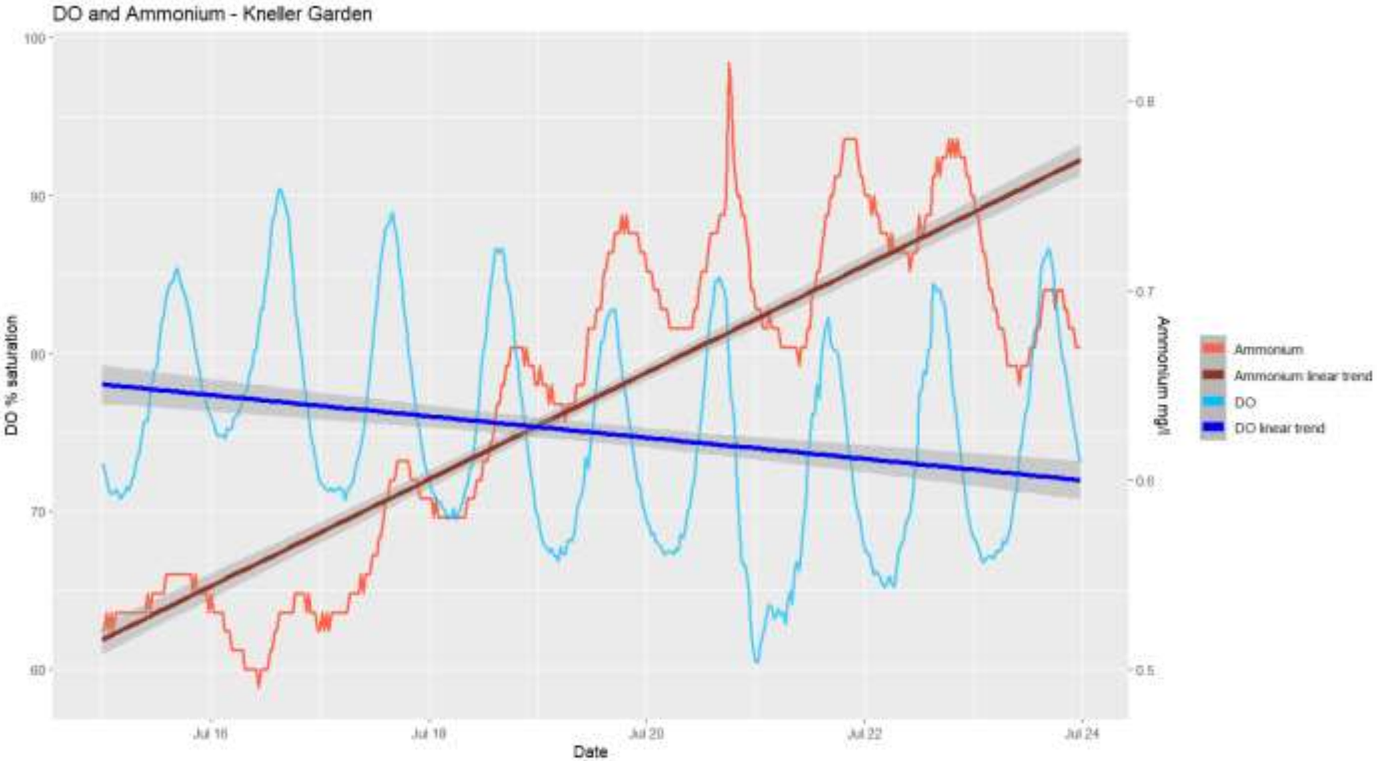


Figure 46: DO % saturation and ammonium, along with associated linear trends, for Kneller Garden CSO over a 1-week period of dry weather in July.

Conductivity

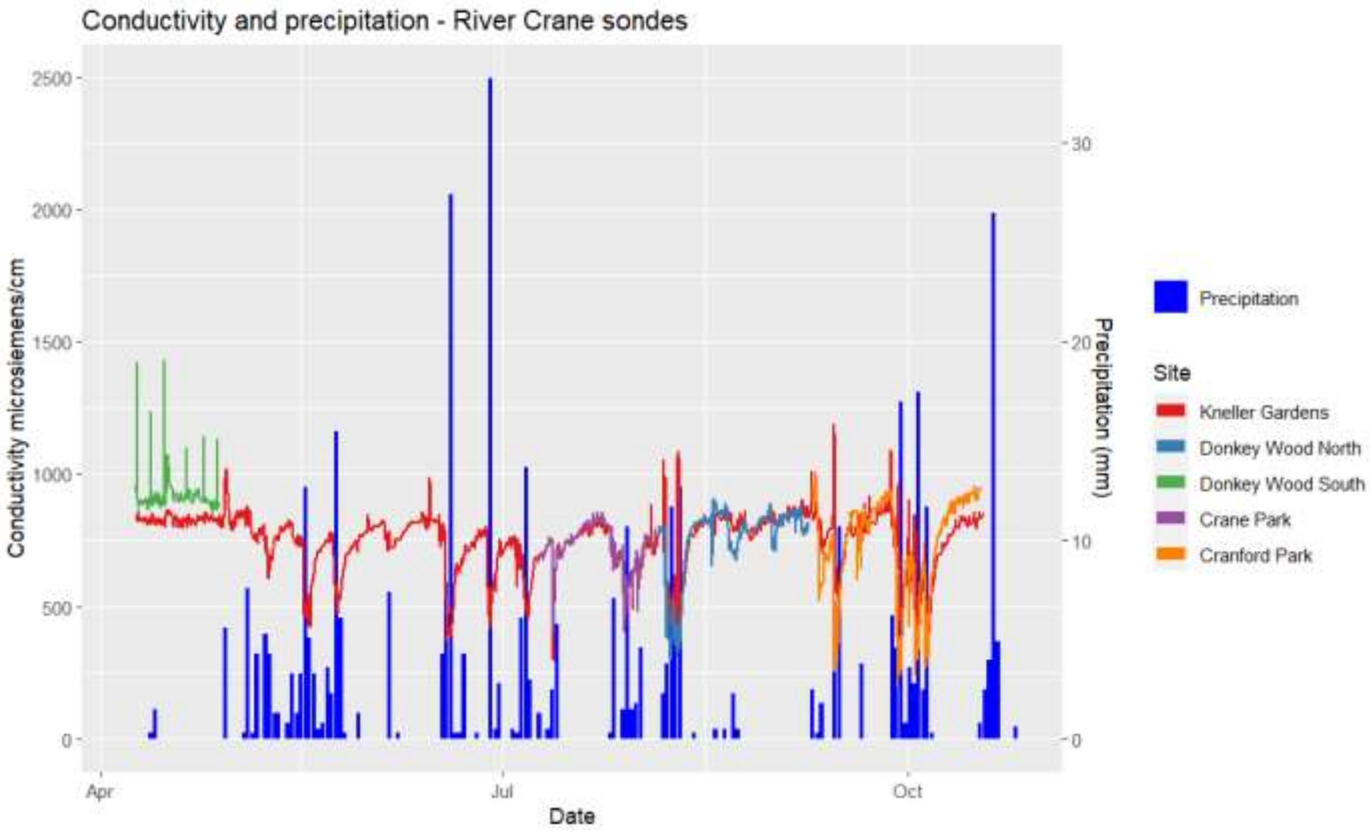


Figure 47: Time series of conductivity for all River Crane sondes, along with total daily precipitation for the period X – X 2021.

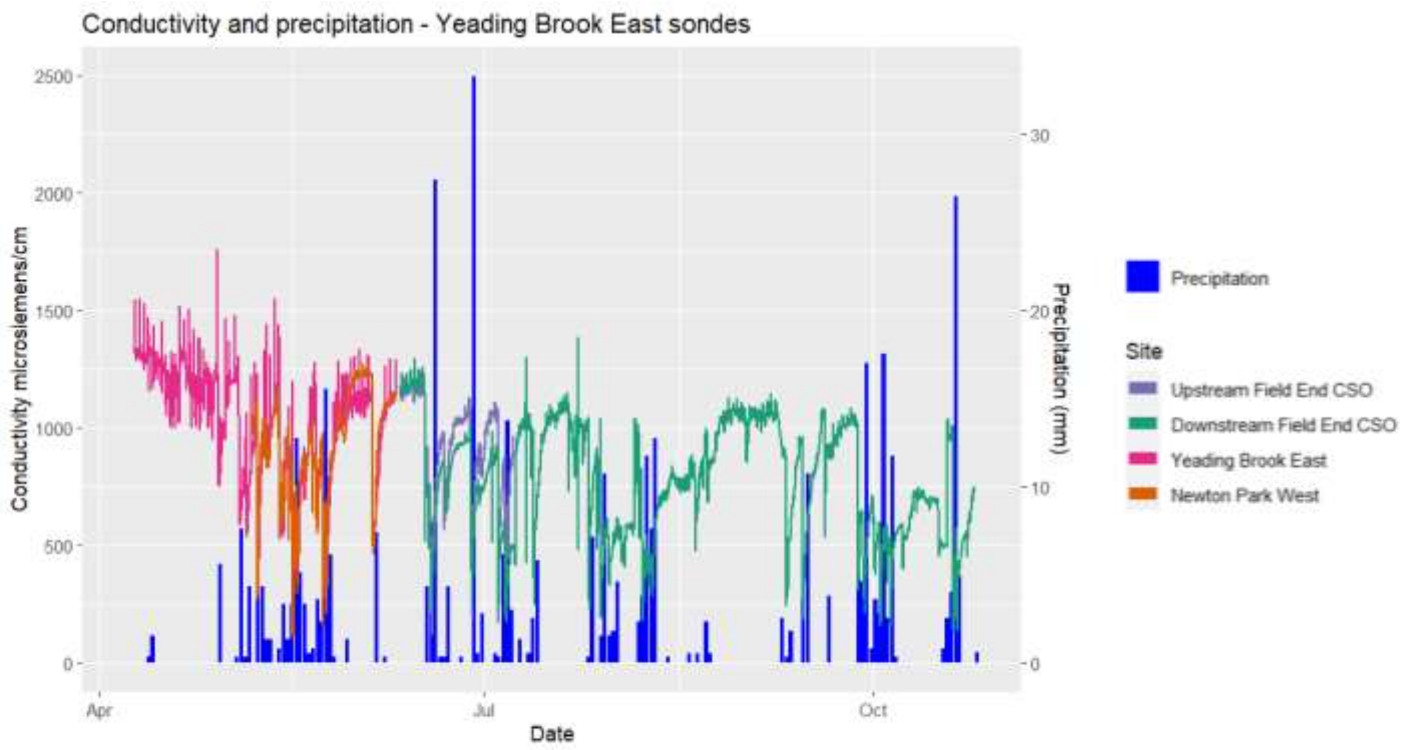


Figure 48: Time series of conductivity for all Yeading Brook East sondes, along with total daily precipitation.

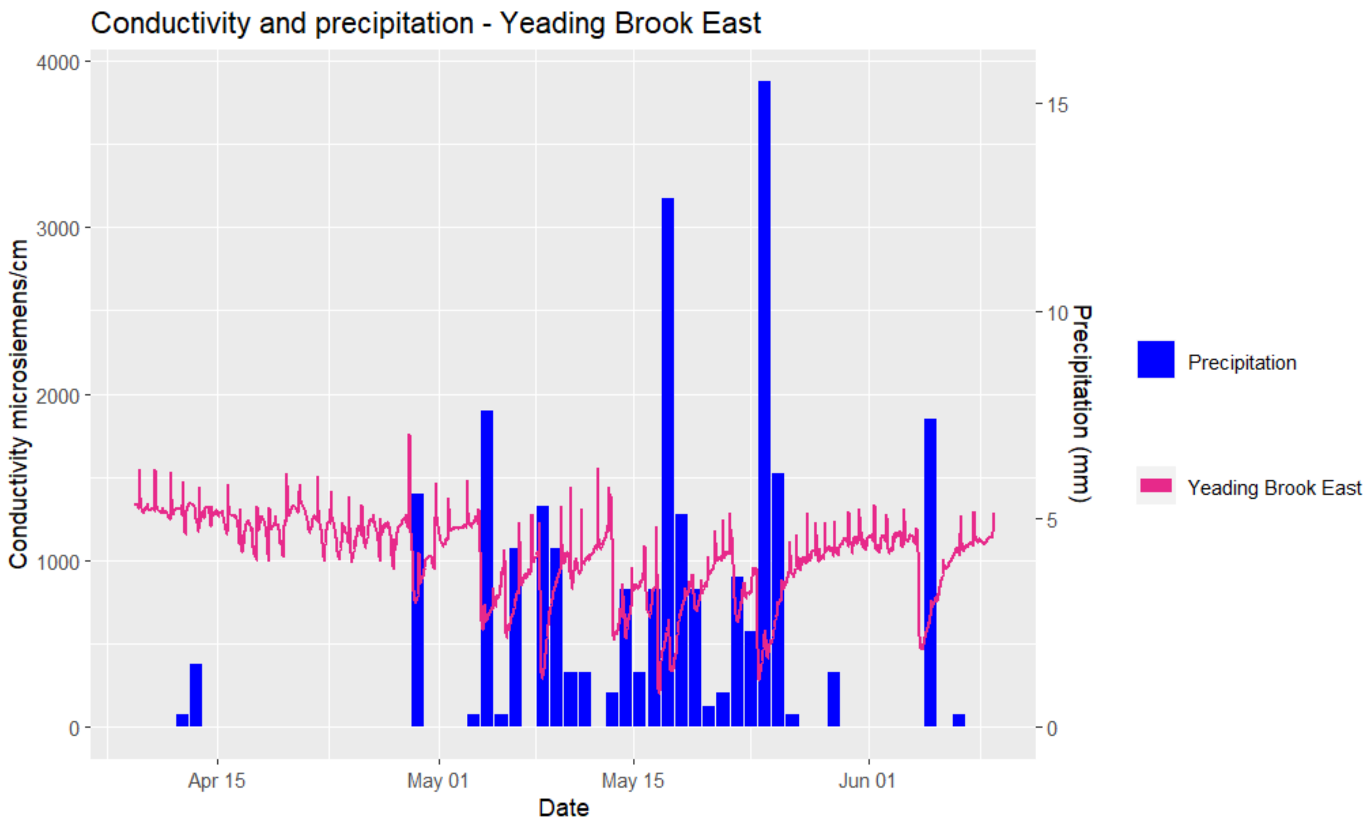


Figure 49: Time series of conductivity for all Yeading Brook East sonde, along with total daily precipitation.

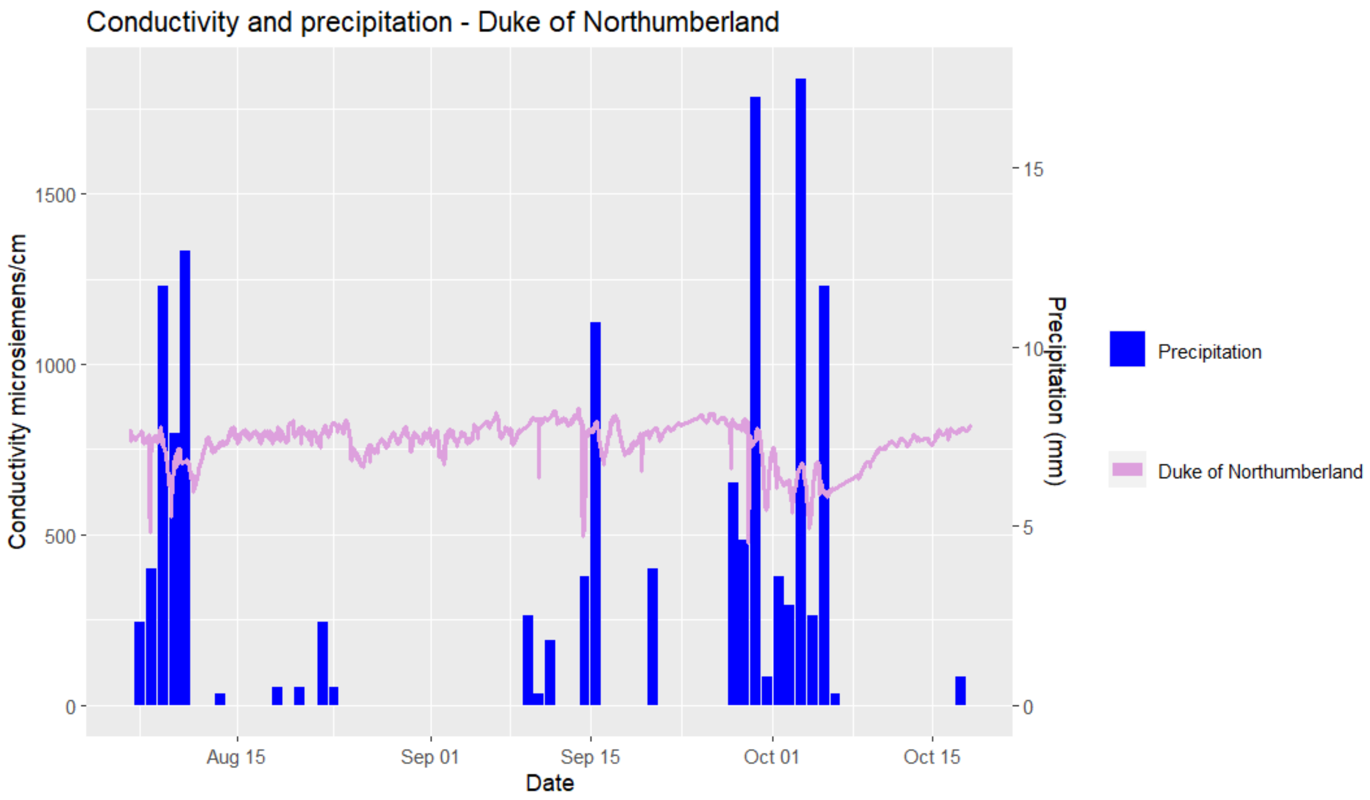


Figure 50: Time series of conductivity for Duke of Northumberland s, along with total daily precipitation.

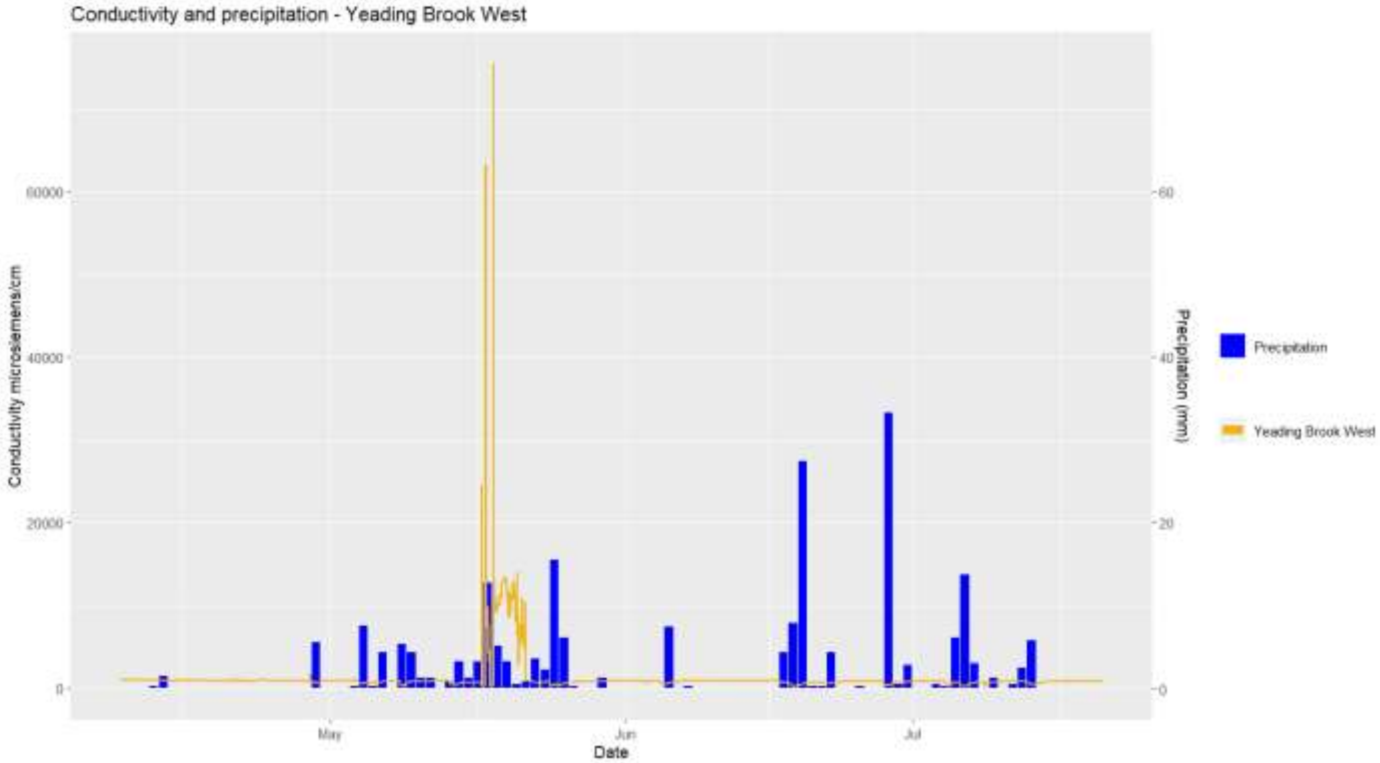


Figure 51: Time series of conductivity for Yeading Brook West, along with total daily precipitation.

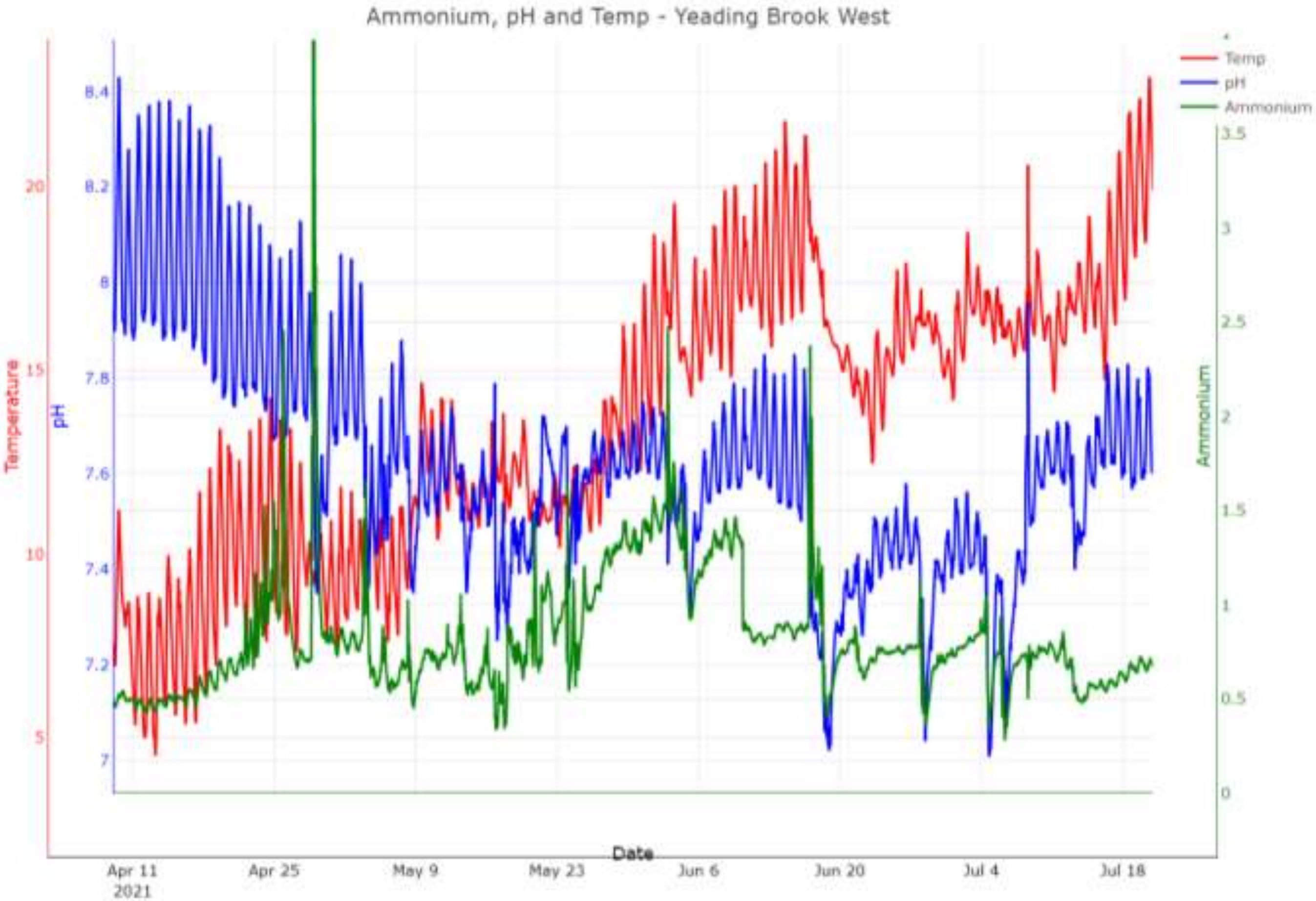


Figure 52: Ammonium, pH and temperature at Yeading Brook West.

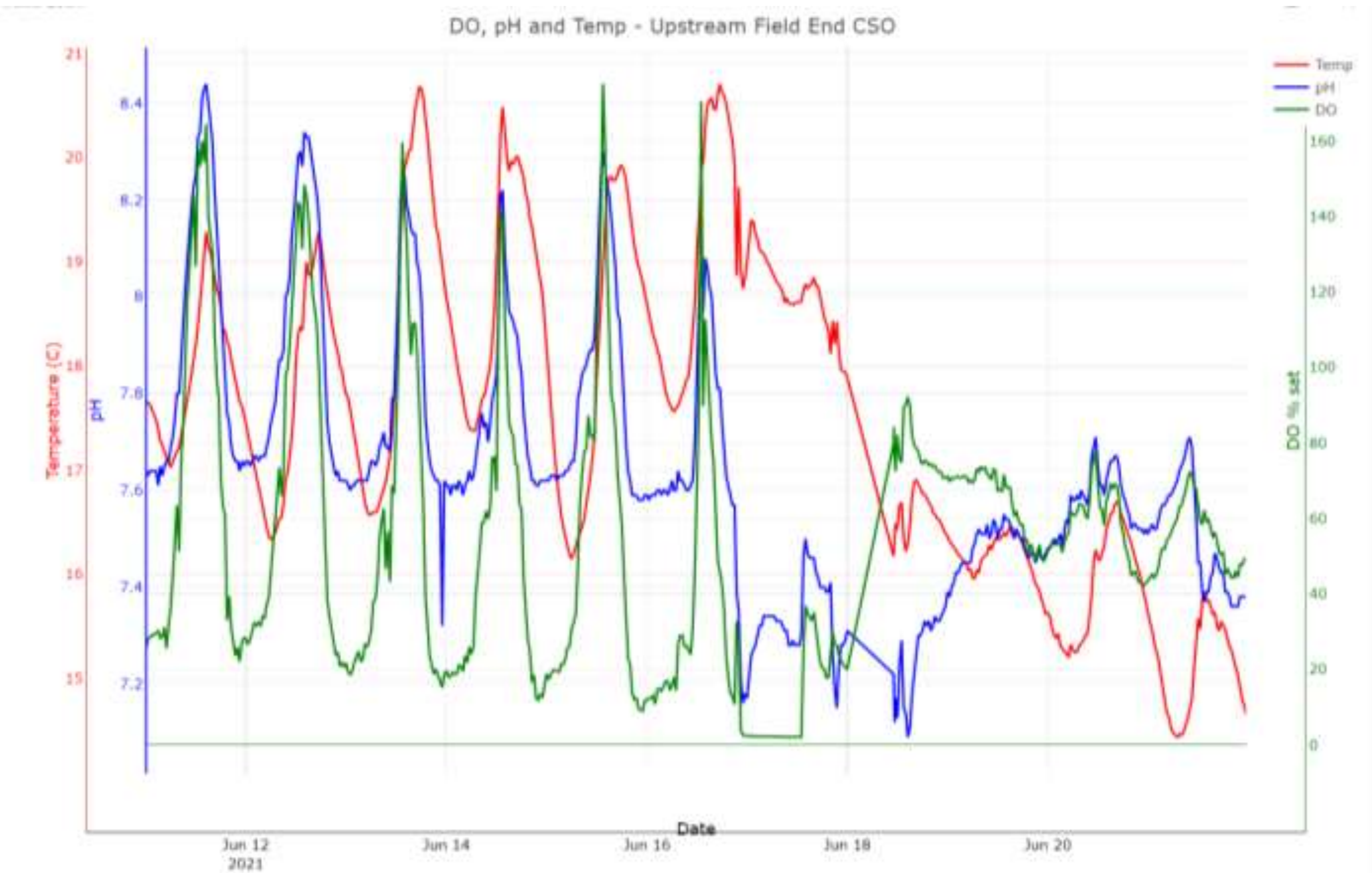


Figure 53: DO, pH and temperature at Upstream Field End.

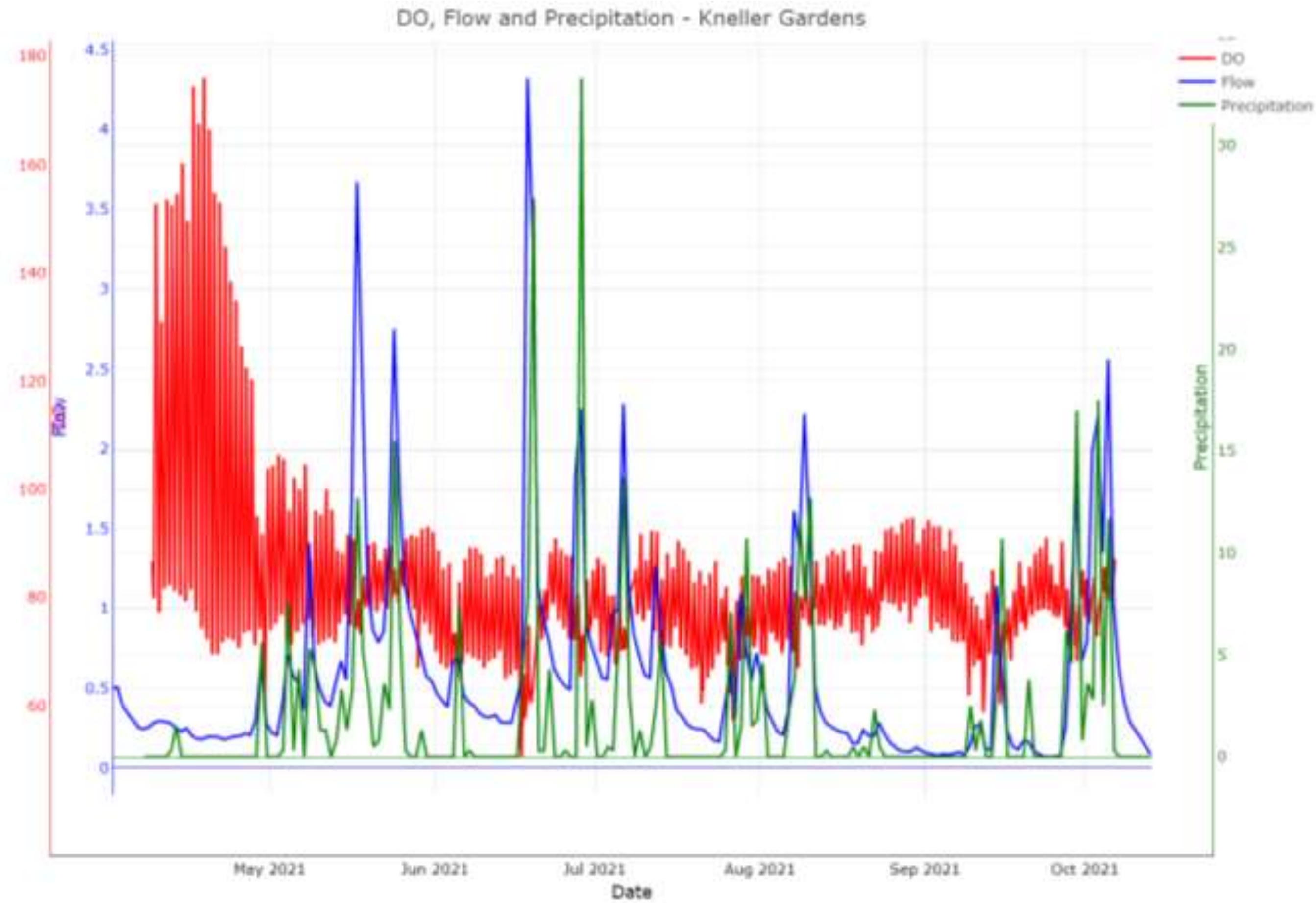


Figure 54: DO, flow and precipitation at Kneller Gardens.

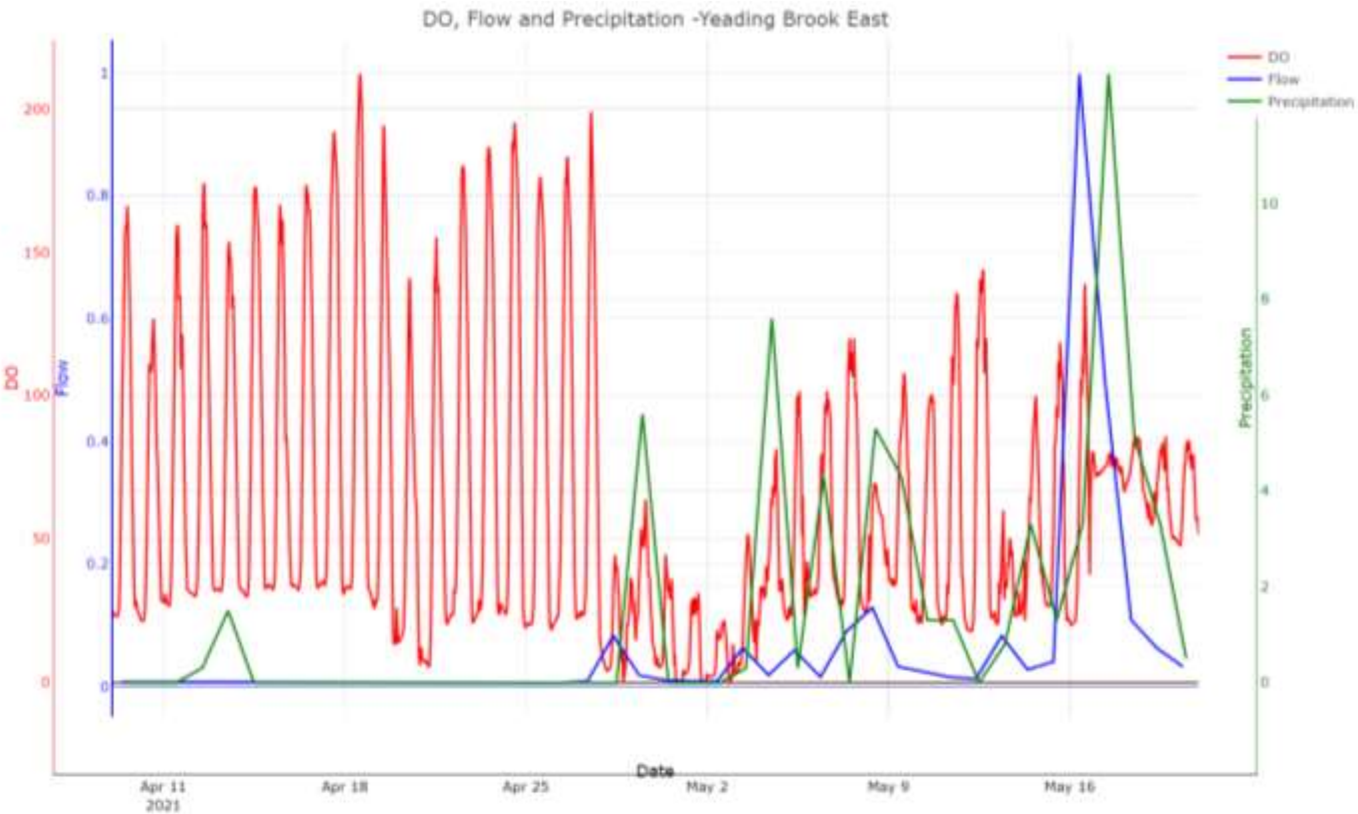


Figure 55: DO, flow and precipitation at Yeading Brook East